A comparative study of activity-related skeletal changes in 3rd-2nd millennium BC coastal fishers and 1st millenium AD inland agriculturists in Chile, South America

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A comparative study of activity-related skeletal changes in 3rd-2nd millennium BC coastal fishers and 1st millennium AD inland agriculturists in Chile, South America

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Abstract

The reconstruction of patterns of physical activities, behaviour, and lifestyle in past populations is one of the goals most often pursued by bioarchaeologists. This study considers the presence of a group of markers of occupational stress (MOS) that are accepted by many in bioarchaeology as representing the impact of physical activity. To examine their presence, two past populations from northern Chile who practised two contrasting subsistence economies such as marine hunting and gathering with agricultural farmers were compared. The skeletal markers analysed were enthesophytes, osteoarthritis, spondylolysis, os acromiale, osteochondritis dissecans as well as changes in size, shape and robusticity of long bones. The aim of this study was to compare the pattern of these MOS in archaic coastal fishers (3rd-2nd millennium BC) with inland agriculturalists (1st millennium AD). One hundred and seventy-five skeletons of adult males and females curated at the Museo Arqueológico San Miguel de Azapa in Arica, Chile were analysed. It was found that early coastal populations were in general significantly more affected by these MOS when compared with later inland agriculturalists thus suggesting that the archaic way of life based on marine hunting and gathering was more physically demanding than that practised by later agricultural and farming populations. The intra-group analysis between sexes revealed that coastal males showed higher prevalence rates of these markers compared with coastal females but comparisons between agricultural males and females failed to demonstrate any significant difference in the prevalence rates for these markers. Thus suggesting a more marked sexual division of labour among the former group compared to the latter. Inter-group sex comparisons revealed that males from both groups were generally similarly affected by the MOS whereas females displayed a more varied pattern. Assuming that these markers result from physical activity and occupation, regardless of the subsistence economy practised, men from both populations performed the most physically demanding activities. Women on the other hand, would have changed their roles in society with the arrival of agriculture, thus getting progressively more involved and participating more in the demanding tasks required by the agricultural way of life. In conclusion, this study showed that the arrival of agriculture in northern Chile resulted in differences in the patterns and prevalence of activity-related pathological conditions.

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Dedication

Le dedico esta tesis a Clotilde Catalina Chiapello de Ponce (mi ITA)
Todo el esfuerzo puesto para alcanzar tan importante sueño en mi vida,
Se lo dedico a mi abuela
A quien amo con todo mi corazón

I dedicate this thesis to Clotilde Catalina Chiapello de Ponce (my ITA)
All the effort made to achieve the most important dream in my life,
I dedicate to my grandmother
Who I love with all my heart

Gracias por ser mi abuela
Gracias por hablar el lenguaje del amor incondicional
Gracias tu entendimiento
Gracias por querer complacer
A vos ITA, my abuela del alma

Thank you for being my grandmother
Thank you for speaking the language of unconditional love
Thank you for your understanding
Thank you for your willingness to please
To you ITA, my soul grandma

Dedication

A los maravillosos papás que con suerte me tocó tener
Norma Varela y Jorge Ponce
Sin ellos hoy no sería quien soy
Y no hubiese llegado a donde estoy

To the wonderful parents that I luckily have
Norma Varela and Jorge Ponce
Without them I would not be who I am
And I would not have gone where I am

Dedication

A los indios de América,
A los que caminaron descalzos
Sobre una tierra que les pertenecía
A los que supieron ser libres
Y dueños de su propio tiempo

To the Native American Indians
Those who walked in bare feet
Over a soil that they owned
Those who were free
And owner of their own time

A los indios de América,
A aquellos que enfrentaron al europeo
Y vieron la caída de sus ídolos y la imposición de otros
A aquellos que fueron esclavizados pagando con su propia vida
Por la codicia y ambición del hombre blanco

To the Native American Indians
Those who faced the Europeans
And lived to see the fall of their idols and the imposition of others
Those who were enslaved and paid with their own lives
For the greed and ambition of white men

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Definitions of abbreviations:

MOS: markers of occupational stress

OA: osteoarthritis

MSM: musculoskeletal stress markers

OD: osteochondritis dissecans

AD: years after Christ

BC: years before Christ

BP: years before present

HR: Humeral Robusticity

FR: Femoral Robusticity

FP: Femoral Platymeric

TP: Tibial Platycnemic

Chapter 1:

Introduction

Chapter 1: Introduction

1.1 Markers of occupational stress: background to study

One of the goals pursued by bioarchaeologists is the reconstruction of the lives of past populations, and particularly their levels of activity (Pearson and Buikstra, 2006). One way to approach this goal is by using the so-called "Markers of Occupational Stress" (MOS). This term is used here to describe specifically enthesophytes, osteoarthritis, spondylolysis, os acromiale and osteochondritis dissecans. These MOS are some of the skeletal changes found in human skeletal remains which are commonly used in combination with biomechanical and geometric properties of long bones to explore past levels of activity. In their "Atlas of occupational markers on human remains" Capasso *et al.* (1998) review over 100 of these markers that have been identified in skeletal remains, and some of those more often used bioarchaeologically will be analysed in the present study.

The study of the impact of occupation on the body can be traced to the beginning of the Industrial Revolution in Europe particularly after the first systematic work on "industrial medicine" and "trade medicine" by the Italian doctor Bernardino Ramazzini and two British followers, Charles Thackrah and William Lane (Kennedy, 1989; Capasso *et al.*, 1998). Over time, studies generated in these fields were complemented with contributions from other sciences such as sports medicine and orthopaedics. Within this context, bioarchaeologists started to turn their attention to the reconstruction of habitual activities from morphological changes in skeletal and dental structures (Kennedy, 1989:129-133).

The study of MOS in bioarchaeology is a relatively recent field of interest. In particular, there has been more interest in the subject over the last three decades with an increasing number of studies aiming to improve methods and provide new approaches (Pearson and Buikstra, 2006). Skeletal markers have been intensively analysed by bioarchaeologists because they are generally viewed as the result of skeletal responses to habitual and repetitive activity (Hawkey and Merbs, 1995; Nagy, 1998) and represent the plasticity of human bone when subjected to stress and strain (Kennedy, 1989). Assuming there is a direct link between MOS and stress due to activity, in conjunction with information provided by other sources such as ethnography or cultural materials associated with skeletal remains, it is an important tool for reconstructing general patterns and levels of activity and even specific occupations in past populations.

Within this context, enthesophytes (or muscle markers) (reviewed in Chapter two, section 2.1) are believed to represent a skeletal response to movement/activity (Larsen, 2002). Although very speculative because of their multifactorial aetiology (Jurmain, 1999), their size and remodelling have often been used a as measure of how sedentary or physically demanding the lives of past populations were. Enthesophytes have been used by bioarchaeologists to infer activities associated with occupations in living and prehistoric populations (Kennedy, 1989). Sometimes specific activities have been suggested from bone changes at a single muscle attachment and at other times bone change at multiple muscle insertions have been used to interpret general patterns and levels of activity. Similarly, these markers have been used to address questions about sexual division of labour (Robb, 1998; Steen and Lane, 1998), and patterns of handedness and asymmetry (Molleson, 1989; Wilczak, 1998; Peterson, 1998; Robb, 1998; al-Oumaoui *et al.*, 2004).

Osteoarthritis is a degenerative condition of the joints (reviewed in Chapter two, section 2.2), and along with enthesophytes, it is believed by many to indicate a pattern of use or "overuse" of the joints of the skeleton due to a heavy workload and demanding physical activities (Larsen, 2002). For example, bioarchaeologists have used osteoarthritis to observe the impact of a change in subsistence economy from hunting and gathering to farming (Bridges, 1989b, 1991a, b, Nagy, 1998, Larsen, 2002). Two important books, "*Paleopathology at the origins of agriculture*" edited by Cohen and Armelagos (1984) and "*Ancient health, skeletal indicators of agricultural and economic intensification*" edited by Cohen and Crane-Kramer (2007) review a number of studies that cover this topic. Osteoarthritis has also been used to answer questions about social status (Groves, 2006; Mayes and Barber, 2008) but, most importantly, osteoarthritis has been used to assess levels of physical activity and sometimes infer specific occupations. One of the pioneering works within this field was that of Angel (1966) who first used the term "atlatl elbow" to signify osteoarthritic changes found in the elbow of males as consequence of spear throwing. Another important contribution was the work of Merbs (1983) on ancient Canadian Eskimos where specific behavioural interpretations were made in conjunction with ethnographic data. In this study, the author also reviewed the presence of spondylolysis, (see Chapter two, section 2.3) a condition resulting from the separation of the neural arches of the lumbar vertebrae from their bodies, believed to be the result of a stress fracture (Whiting and Zernicke, 2008). Spondylolysis has been commonly used as a MOS to indicate vigorous movements of the spine and strenuous activity (Merbs, 1983, 1996a; Arriaza, 1997; Fibiger and Knüsel, 2005).

Additional indicators of human behaviour have also been interpreted from the presence of os acromiale (see Chapter two, section 2.4), a condition resulting from the non-fusion of the acromial end of the scapula (Resnick, 2002c). Os acromiale is believed to result from repetitive mechanical stress and trauma in the region of the developing acromion and, although bioarchaeologists have suggested a number of physical activities as the cause of its presence, the original idea of Stirland (1993, 2000) deserves special mention. This author suggested that the practice of archery during the medieval period may have contributed to the high prevalence of os acromiale in a group of skeletons recovered from the Mary Rose, a sunken British warship dated to the sixteenth century. The author used historical documents to support the presence of these professionals among the cabin crew.

Osteochondritis dissecans (see Chapter two, section 2.5) is perhaps one of the markers of occupational stress least acknowledged by bioarchaeologists because of its low frequency in human skeletal remains. This is a condition where, due to underlying trauma, a small fragment of articular cartilage, or both cartilage and subchondral bone, detaches gradually from its normal position on the joint (Ortner, 2003). Osteochondritis dissecans has been used by bioarchaeologists, along with other MOS, to support evidence of unique patterns of trauma (Stirland, 1996), and on stressful lifestyles related with military activity (Knüsel, 2000) among others.

Finally, although not strictly considered a marker of occupational stress, the study of external dimensions of long bones (see Chapter two, section 2.6) has been used by bioarchaeologists as a tool to investigate patterns of physical activity in prehistoric populations in a variety of archaeological samples (Pearson and Buikstra, 2006). Based on the influential studies of Julius Wolff (1836-1902), a German orthopaedic surgeon, the so-called "Wolff's Law" is often used to describe how bones respond to mechanical stimuli by remodelling their internal and external structure in the direction of the functional stress (Pearson and Lieberman, 2004; Ruff *et al*., 2006). Bioarchaeologists have carried out a comprehensive number of studies involving numerous external measures and cross-sectional geometrical properties of long bone with the objective of exploring patterns of mobility (Ruff, 1987; Stock, 2006) and the transition from hunter gathering to farming across time and space (Brock and Ruff, 1988; Larsen and Ruff, 1991; Bridges, 1991b; Larsen *et al*., 2007 and many more).

This brief review summarises how a small number of MOS have been used to attempt to reconstruct lifestyles of past populations resulting in many studies. There are, however, some limitations in using MOS which have to be acknowledged and recognised. Firstly, although bone changes can result from subjecting the skeleton to repetitive tasks over a long period of time, Jurmain (1999) has emphasised that the many varied activities that human beings put their bodies through during their lives should similarly be considered. On the other hand, Merbs (1983) has argued that despite the variety of activities to which humans expose their bodies, even during one entire day, there are certain activities that are performed repetitively over and over again if they are necessary for survival. In this context Arriaza (1995a) emphasised that because food is essential to survival, the pursuit of dietary needs can became a primary determinant of behaviour.

Secondly, apart from the type, duration and range of activities performed by human beings during their lives, there are other factors such as ethnicity, sex, age, diet and genetics that may affect or influence the way people practise a specific activity, along with how the activity affects the body (Jurmain, 1999). Being able to evaluate the role played by these individual variables in human skeletal remains can prove challenging.

Thirdly, it has been emphasised that the desire for interpreting behaviour from the skeleton has often led to circular arguments. For instance, isolating the presumed activities that triggered the conditions with the limited ethnographical data or using the "best fit" idea. The skeletons show osteoarthritis of the elbow, the ethnographical data supports the presence of atlatls; therefore the condition was caused by throwing an atlatl, which suggests that throwing atlatl can lead to osteoarthritis of the elbow. This approach is in part due to bioarchaeologists not considering the clinical data available to understand the underlying aetiological factors involved in their expression (Jurmain, 1999). On the other hand, according to Larsen (1997:164), although the information provided by clinical studies should always be considered in bioarchaeological studies, comparisons of both types of data are not always straightforward as the latter deals with more visible and often subtle changes, which are not always noticed by clinicians in radiological examinations. However, having objective data from clinical studies of activity related skeletal change must stand as a base for this type of research.

According to Hawkey (1998), Steen and Lane (1998) and Roberts and Manchester (2005:144), using multiple MOS together in studies of the remains of past people may be a solution to this criticism, providing strength to the arguments and ensuring more reliable interpretations. Examples of studies of multiple markers of occupational stress are those of Merbs (1983), Ruff (1987), and Angel *et al.* (1987). However, this line of approach has also been criticised by Jurmain (1999) who argued that using either a single marker or a combination of them does not necessarily give more rigour to activity interpretations; using lots of weak data does not ensure greater precision.

Although the study of MOS, and their validity as a source of information for past activity has received severe criticism by Jurmain (1999), to the point of questioning its further development, they are still studied, and the author of this research feels it is a worthy field to explore providing that various forms of data (clinical, historical, ethnographical, biochemical and archaeological) are interrelated. More work on past and present populations is clearly needed to clarify how the various forms of data are inter-related as well as what activities are responsible for the development in life of the features observable in skeletal populations (Pearson and Buikstra, 2006).

1.2 Aim

This study aims to compare the presence of activity-related skeletal changes in two prehistoric Amerindians populations from Chile, in South America. For this purpose, enthesophytes, osteoarthritis, spondylolysis, os acromiale, osteochondritis dissecans and external measurement of long bones will be used. As explained above, these markers are among those most often used by bioarchaeologists to explore a number of topics including the arrival of agriculture, sexual division of labour, patterns of handedness and asymmetry as well as to compare contrasting lifestyles. The skeletal remains used for this study derive from Chile and belong to early archaic coastal fishers dating to the 3rd-2nd millennium BC and inland agriculturalists dating to the 1st millennium AD. The rationale for choosing these samples was that these skeletons belonged to individuals from contrasting subsistence economies. Despite settling only approximately 20km apart, these coastal fishers and inland agriculturalists exploited resources from two different ecological systems, the Pacific coast and the Azapa valley, both from northern Chile.

Assuming that markers of occupational stress (MOS) are a useful tool for comparing general patterns of activities between populations that practised different subsistence economies, one should expect to observe a difference in prevalence rate of these indicators between the populations, as demonstrated by a number of similar studies (Larsen, 1984; Ruff *et al*., 1984; Bridges, 1991a, b; Larsen *et al*., 2007). Similarly, assuming that a more mechanically demanding lifestyle leads to a greater prevalence of osteoarthritis and other skeletal changes (Larsen 1997:194), a difference in prevalence of these indicators should be expected, providing both populations were subjected to different demanding work repertoires. In line with this, the null hypothesis to be tested in this study is that there is no significant difference in the presence of markers of occupational stress between the two populations under study.

For the purpose of comparison, adult individuals of both sexes and from different age categories were analysed. Only adult individuals were chosen because sub-adults may not have taken part in regular physical activities for long enough to manifest activity-related skeletal changes. Comparisons were performed according to sex and age because these variables are known to influence the expression of the chosen markers (Bridges, 1992; Jurmain, 1999).

1.3 Objectives

At a more specific level, the objectives of the research are:

- To compare the distribution and prevalence of multiple activity-related skeletal changes between coastal fishers and inland agriculturalists
- To examine the distribution and prevalence of the MOS between sexes, according to age and according to laterality (or side affected)

Excluded from the objectives were any attempts to identify or reconstruct the specific type of activity, occupation or habitual behaviour that could have produced the skeletal changes. This would have been highly speculative and, instead, general patterns and levels of activity were compared.

Following this introduction, the next chapter reviews the MOS selected for analysis. Chapter three looks at the material used for this study. Chapter four describes the methods used for analysis. Chapter five presents the results following the order listed at the beginning of this section. Chapter six is the discussion of the results and the conclusion of the study is presented in Chapter seven.

Chapter 2:

Markers of occupational stress (MOS)

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This chapter looks at each of the MOS, reviewing the clinical literature and includes a summary of the diagnostic criteria, epidemiology and symptoms of each of the conditions. Each section then reviews how bioarchaeologists have used these MOS to help to understand physical activity in past populations and provides a brief summary of the limitations of their use and future research for their development.

2.1 Enthesophytes

In this section information is provided about the clinical aspects of entheses and enthesophytes, and particular attention is given to the underlying aetiological factors for enthesophyte formation. The bioarchaeological evidence is also reviewed in light of the importance given to enthesophytes as potential markers for addressing past physical activity and their limitations.

2.1.1 Definition

The insertion site of ligaments and tendons into bones is defined as an enthesis (from the Greek *enthesis* meaning insertion) (Fig 1).

Figure 1: Az140 T19 showing enthesophytes at the *M. flexor digitorum brevis* of both calcanei (plantar fascia).

The same as roots are to trees; entheses are important anatomical structures that ensure skeletal anchorage, stress dissipation and load distribution (Benjamin *et al*., 2006). These functions are possible because the transmission of forces from tendon and ligament to bone is accompanied by a gradual transition of the forces through four histologically distinctive zones; dense fibrous connective tissue is replaced successively by uncalcified fibrocartilage, calcified fibrocartilage and bone (Benjamin *et al.*, 1992; Benjamin and Ralphs, 1997).

The analysis of entheses has not been seriously addressed by clinicians and this could be due in part to the fact that they do not always produce distinctive symptoms for the person and are rarely life threatening (Jurmain, 1999:143), but also because far less attention has been paid to tendons and ligaments than to bone. On the contrary, entheses can certainly be the source of considerable pain and disability and therefore of clinical significance to orthopaedic surgeons when patients present with avulsion fractures or rupture of ligaments or tendons that need surgical reattachment to bone (Freemont, 2002; Benjamin *et al*., 2006).

2.1.2 Terminology and classification

An enthesopathy or enthesophyte is a term used to define abnormal skeletal change at an enthesis (Freemont, 2002). A number of clinical terms also used include “bony spurs”, “bony outgrowths” (Benjamin *et al*., 2006), “bony prominences” (Resnick, 2002e), “calcific overgrowth” (Shaibani *et al*., 1993), and “calcific formations” (Varghese *et al*., 2006).

In bioarchaeology, enthesophytes are usually called musculoskeletal stress markers (MSM). This terminology applies not only to the hypertrophic enthesophytes seen at specific attachment sites of ligament and tendons (Hawkey and Merbs, 1995, Wilczak, 1998), but also to the less described destructive forms characterised by pitting and cavitations (Mariotti *et al*., 2004; Molnar, 2006).

There are numerous classifications of entheses and enthesophytes. For instance, Benjamin *et al.* (2006) recognises two types of entheses on the basis of the structure to which they attach. Fibrous entheses connect the tendon or ligament to the periostium with dense fibrous connective tissue (no evidence of fibro-cartilaginous differentiation) and fibro-cartilaginous entheses involve chondrogenesis and the presence of the four zones mentioned earlier: pure dense fibrous connective tissue, uncalcified fibrocartilage, calcified fibrocartilage and bone.
Enthesophytes have been classified according to the factors that produce them. Whereas Freemont (2002) distinguishes two simple types, inflammatory and non- inflammatory enthesophytes, Ruhoy *et al*. (1998) make a distinction between traumatic, degenerative, inflammatory and metabolic enthesophytes.

2.1.3 Diagnostic criteria

Clinically, conventional radiographic observation and histological analysis have been used traditionally to assess the presence of enthesophytes in patients and cadavers. However, modern techniques such as magnetic resonance imaging (MRI) and Doppler ultrasonography are also applied routinely to understand the pathophysiology of these bone changes (Varghese *et al*., 2006; Benjamin *et al*., 2006).

In archaeology, however, the advantage of visual examination of skeletons without the presence of soft tissue provides an exceptional opportunity to observe all bony surfaces and changes associated with this condition (Rogers *et al*., 1997).

2.1.4 Epidemiology

(i) Prevalence

There are only a few population based studies addressing the general prevalence of enthesophytes. The reason for this may be because the condition is not life-threatening and clinicians are more interested in treatment. However, an epidemiological study conducted by Voudouris *et al*. (2003) with 3670 adult patients visiting the

Rheumatology Department of a Greek Hospital in Thessaloniki revealed that evidence of an enthesophyte in at least one of the four regions analysed (pelvis, knee, ankle and shoulder) was present in 15.9% (585 patients). Analysis of prevalence rates according to these locations revealed that the pelvis (iliac crests, greater trochanters, pubic symphyses and pubic rami) was the site most affected with enthesophytes in 46.0% of people (163/355), followed by the knee (patella) at 22.2% (37/166). Enthesophytes on the ankle (calcaneus) were present in 17.2% of people (23/134) and lastly the shoulder (humeral head) in 15.4% (18/117). In a different study, Freemont (2002) suggested that the commonest place for enthesophytes seen in nearly 25% of all ages of the adult population from the USA is the calcaneus at the site where the Achilles tendon attaches (Fig 2), the so-called calcaneal spur.

Figure 2: Az140 T8 showing enthesophyte formation at the Achilles tendon insertion of both calcanei

As enthesophytes can be present anywhere in the skeleton their prevalence might change from site to site as demonstrated in these studies. Furthermore, the absence of symptoms, as reviewed in section 2.1.5 of this chapter, could indicate that the actual prevalence in the general population might be higher than observed.

(ii) Enthesophytes and age

It has been suggested that formation of enthesophytes starts during young adulthood. However, this will depend on numerous variables. For instance, in a population study of 359 individuals from two small villages in Russia, Kalichman *et al*. (2007) found that the onset age of hand enthesophytes was 25 years. Woods *et al.* (2002) carried out an audit of injuries in professional football players and found that most tendon-related conditions, including enthesophytes, of the lower limbs started at the age of 17 years. This suggested that a slight variation in onset age may be present in different groups depending on the specific enthesophyte or enthesophytes analysed, as well as sport participation, and duration and intensity of the physical activity.

The presence of enthesophytes is generally positively correlated with increasing age. A number of studies have supported this trend (Shaibani *et al*., 1993; Rogers *et al*., 1997; Woods *et al*., 2002; Mariotti *et al*., 2004). For instance, Kalichman and co-workers (2007) analysed the relationship between hand enthesophytes and age in 359 individuals from the villages of Chuvashia and Bashkortostan in Russia. By creating an overall score based on radiograph observations of midshaft enthesophytes of both hands, the authors found that, starting at about the age of 25 years enthesophyte formation increased with age linearly on average in both sexes. On the other hand, despite hand enthesophytes showing age-related changes, the authors found that a significant number of individuals did not develop enthesophytes at all up to the age of 85 (ages ranged from 18-90). Unfortunately no further information was given regarding the prevalence and significance of those that never developed enthesophytes. Shaibani *et al*. (1993) observed that the frequency of entheses on the calcaneus (Achilles tendon), and in the plantar fascia area, on the patella and the iliac crest in 19th/20th century skeletons from the Hamann-Todd collection, Cleveland, Ohio, USA, remained inconsistent after the age of 60 years independent of the skeletal site observed. Furthermore, absence of a correlation of Achilles tendon enthesophytes with increasing age was observed in a cross sectional study conducted by Longo e*t al.* (2009) in 178 veteran athletes from Poznań (Poland) aged 35-94 years.

(iii) Enthesophytes and sex

Enthesophyte formation also tends to be correlated with sex, with the exception of research by Longo *et al.* (2009) who did not find sex differences in Achilles tendinopathy between male and female Polish athletes (110 men and 68 women). The studies of Rogers *et al*. (1997), Mariotti *et al.* (2004) and Kalichman *et al.* (2007) found enthesophytes to be sex correlated. The first author analysed 337 adult skeletons dated from 16th century Britain and found that the prevalence of enthesophyte formation at 14 ligament insertion sites was higher for males than for females. Similarly, Mariotti *et al.* (2004) analysed the presence of numerous enthesophytes on the clavicle, humerus, radius, ulna, femur, tibia, patella and calcaneus and found a higher prevalence in males, with the exception of *M. brachialis* which perhaps was related to occupational differences between the sexes. *M. brachialis* inserts in the ulnar tuberosity and flexes the forearm. This enthesophyte formation was found in 4 out of 34 female skeletons compared with none out of 40 males. In the same way, Kalichman *et al.* (2007) observed that age explained 45% of the enthesophyte variation in the hands of males and only 25% in the females thus reflecting reaction to musculoskeletal stress between the sexes. In contrast, Voudouris *et al*. (2003) found that a significantly higher prevalence of females (60%, 349/585) were affected by pelvic, patellar, calcaneal and humeral enthesophytes compared to males (40%, 236/585). Despite admitting to expecting the opposite trend, the authors explained that the pattern obtained in these Greek patients resulted from the group being self-selected and seen in their clinic, rather than being a less biased and more population wide sample.

(iv) Other aetiological factors

There is no single explanatory cause for the presence of enthesophytes. For instance, trauma as well as a number of pathological conditions including degenerative (osteoarthritis), inflammatory (ankylosing spondylitis, psoriatic arthritis, Reiter's syndrome) and metabolic (acromegaly) disease categories have been linked to the formation of enthesophytes. Furthermore, spinal and extraspinal enthesophytes are consistent manifestations of DISH (diffuse idiopathic skeletal hyperostosis) (Ruhoy *et* *al*., 1998). However, physical activity also seems to be a forgotten aetiological factor in clinical contexts, as a large majority of clinicians do not mention it as a causative factor for enthesophytes. All these potential aetiological factors will now be reviewed.

(a) Trauma

The aetiology of enthesophytes is associated with trauma following the tear or rupture of a tendon or ligament. It has been observed that a single heavy loading episode or repetitive episodes of extreme load can cause avulsion fractures. These occur under very heavy loading when bony protuberances are torn off from the surrounding bone instead of the tendon or ligament being ripped from the bone (Freemont, 2002). However, entheses are very stable and strong structures. A common place for avulsion fractures is the anterior talofibular ligament of the ankle joint (Kumai and Benjamin, 2002). It has also been suggested that spontaneous rupture of entheses can also take place, although in such rare cases patients usually present with other underlying pathological conditions of the bones (Ruhoy *et al*., 1998). For instance, Varghese *et al*. (2006) reported on a 46 year old man who had suffered a rugby injury in his knee with a partial rupture of the quadriceps tendon. Seven years after his injury radiographic analysis showed new bone formation in the form of “whiskers” on the superior aspect of the patella compatible with enthesophytes.

(b) Degenerative diseases

In addition, enthesophytes can also occur as consequence of degenerative diseases, or common conditions of advancing age (Benjamin *et al*., 1992; Ruhoy *et al*., 1998; Resnick, 2002d, e). For instance, Rogers *et al.* (1997) found a positive correlation between enthesophytes and osteoarthritis formation at a number of spinal and extraspinal joint sites and enthesophytes at 14 ligament insertion sites in 337 adult skeletons. The role of enthesophytes in osteoarthritis of the hand has also been highlighted. For instance, Slobodin *et al.* (2007) observed that prominent enthesophytes of the collateral ligaments and extensor tendons have been consistently a common feature associated with osteoarthritis of the small joints of the hand. Similarly, Kalichman *et al.* (2007) found that both enthesophytes and osteoarthritis of the hand showed age related changes.

(c) Inflammatory conditions

Certain inflammatory conditions can also lead to enthesophyte formation. Inflammatory enthesophytes are present in certain rheumatic diseases such as the so-called seronegative spondyloarthropathies. These are a group of inflammatory disorders that include ankylosing spondylitis, Reiter's syndrome, psoriatic arthritis and spondyloarthropathies associated with inflammatory bowel diseases (Stafford and Youssef, 2002). In general, they produce "enthesitis" or inflammation of muscles, tendons and ligaments at the entheses they attach to on bone as well as inflammation of certain synovial, cartilaginous and fibrous joints. The first signs are osseous erosions with consequent bone formation in an attempt to repair the lesions. This in turn leads to proliferative enthesophyte formation and progressive ankylosis of the joints as observed in ankylosing spondylitis. Particularly affected areas are some of the less movable joints such as the sacro-iliac. The spine can also be severely affected (especially in those suffering from ankylosing spondylitis) where the formation of bony spurs known as a syndesmophytes can lead to a complete ankylosis and immobilisation of the spine (Ruhoy *et al*., 1998; Freemont, 2002). Other common inflammatory entheses may be found on the calcaneus, iliac crest, femoral trochanters, patella and humerus.
Although the causes of seronegative spondyloarthropathies remain far from being fully understood, the presence of the HLA (Human Leukocyte Antigen) gene, an antigen in blood commonly associated with psoriatic arthritis and ankylosing spondylitis as well as urogenital or gastrointestinal infection, plays an important role in their aetiology and the manifestation of inflammatory enthesophytes (Stafford and Youssef, 2002; Freemont, 2002).

(d) Metabolic disorders

Certain metabolic disorders, including acromegaly and diabetes mellitus, also play a role in enthesophyte formation. The former condition results from an overproduction of growth hormone which in turn leads to bone proliferation at tendon and ligament attachments (Ruhoy *et al*., 1998). The commonest entheseal places affected by acromegaly are the calcaneus (plantar and posterior spurs), clavicle (coraco-clavicular ligament), patella as a "whiskering" formation, humeral tuberosities and femoral trochanters among others.

Diabetes mellitus can also produce similar entheseal abnormalities by increasing the presence and frequency of bony outgrowths and excrescences (Slobodin *et al*., 2007). Crystal deposition in tendon and ligaments such as calcium pyrophosphate and hydroxyapatite can also lead to enthesophyte formation at single or multiple attachment sites. These calcifications usually produce ligament disruption, degeneration and thickening of the enthesis with inflammatory changes that can lead to necrosis (Ruhoy *et al*., 1998; Freemont, 2002). Finally, intoxication with fluoride secondary to a high content of this mineral in drinking water can produce calcification of ligaments and entheseal changes as observed in specific endemic locations of the world, particularly India (Ruhoy *et al*., 1998). Similar entheseal changes are observed with other metabolic conditions including hypervitaminosis A and osteomalacia (Freemont, 2002).

(e) Diffuse idiopathic skeletal hyperostosis

Enthesophytes can also be formed in association with diffuse idiopathic skeletal hyperostosis (DISH). This is characterised by ossification of the anterior longitudinal ligament of the spine producing ankylosis of variable numbers of vertebrae, which gives it a "flowing candle-wax appearance" to the anterior aspect of the vertebral column (Fig 3) (Resnick, 2002a). The extraspinal manifestations of DISH are characterised by ossification of ligaments and tendons, producing prominent enthesophytes. Although they can be present anywhere in the skeleton, their appearance and distribution is characteristic at certain locations and they mostly show a symmetric distribution affecting the body bilaterally (Resnick, 2002a).

In the upper limb the most frequently affected areas are the elbows, particularly the *M. triceps* insertion into the olecranon, the shoulders and humerus. Enthesophytes at the deltoid tuberosity of the radius, the greater tubercle in the humerus as well as the coraco-clavicular ligament attachment in the clavicle are also common. In the lower limb, enthesophytes can occur at the entheses for the iliolumbar, sacroiliac and sacrotuberous ligaments as well as for the insertion of the *M. iliopsoas* on the lesser trochanter of the femur (Ruhoy *et al*., 1998).

Figure 3: HB 257 showing ossification of the anterior longitudinal ligament. Late medieval Blackfriars, Gloucester, England

Enthesophytes on the heel are found on the posterior and inferior surfaces of the calcaneus, particularly at the entheses of the Achilles tendon and the plantar aponeurosis (Resnick, 2002a). In the foot, the enthesophytes tend to be present on the dorsal surfaces of the talus, dorsal and medial aspects of the navicular bone, lateral and plantar surfaces of the cuboid and at the base of the fifth metatarsal. The patella and knee usually show enthesophytes at the site of the insertion of the *M. quadriceps femoris* into the patella and the patellar ligament into the tibia, producing patellar hyperostosis and irregularities in the tibial tuberosity (Ruhoy *et al*., 1998; Resnick, 2002a). Although some authors consider DISH a possible degenerative condition and others a metabolic disorder, the factor or factors that trigger the development of DISH are still unknown, as indicated by the term “idiopathic” (Freemont, 2002).

(f) Physical activity, occupation and mechanical factors

Of more importance for the purposes of the present study is the relationship between enthesophyte formation and physical activity. Paradoxically, it is remarkably evident how the orthopaedic literature pays little attention to the possibility that physical activity, occupation and other mechanical factors could be responsible for the formation of enthesophytes. For this reason, the information available on enthesophytes associated with specific activities comes from studies carried out in other fields such as kinesiology, sports medicine, occupational medicine, biomechanics and applied anatomy (Eller *et al*., 1992; Karlsson *et al*., 1995; Woods *et al*., 2002). Terms such as “tennis elbow”, “golfer’s elbow”, “little league elbow” and “jumper’s knee” are common examples of synonyms applied to enthesophytes at specific skeletal locations in sports science literature (Yu *et al*., 1995; Whiting and Zernicke, 2008; Longo *et al*., 2009).

Nevertheless, over the last few years a number of authors have emerged from the clinical field addressing general aspects of tendon and ligaments insertions although not always referring to enthesophyte formation. This is the case with Benjamin and co-workers who have shown a growing interest in this topic. For instance, in some of their recent work Benjamin and Ralphs (1997) suggested that the growth of a tendon or ligament is limited by the force produced by the muscle. This principle is supported by Wolff’s law (Pearson and Lieberman, 2004; Ruff *et al*., 2006), which underpins the theory that muscle, tendon and ligament strain are considered the most important forces responsible for changes in shape of bones and the subsequent formation of tuberosities, tubercles and crests. Wolff’s law and the idea “form follows function” will be discussed in section 2.6.1 of this chapter. In this context, it is therefore understood that stress deprivation and immobilisation produce significant reduction in the strength and the mechanical properties of tendons and ligaments (Benjamin and Ralphs, 1997) and consequently bone (LeBlanc *et al*., 2007). From this point of view it would be expected that fit and active people such as gymnasts and other athletes would be more at risk of developing enthesophytes. Experimental studies involving immobilisation of joints and bones produces deterioration of the mechanical properties of tendons and ligaments (Yasuda and Hayashi, 1999).

In their study of the relationship between entheses, exercise and mechanical load, Benjamin *et al.* (2006) suggested that tendons respond to biomechanical changes in load such as compression and relaxation and that the presence of differential strain can induce enthesophyte formation. Therefore Benjamin *et al*. (2006) considered that a combination of mechanical and biomechanical factors is a more plausible causal explanation than attributing enthesophyte formation to inflammatory processes. In line with this idea, Kumai and Benjamin (2002) have carried out routine histological analysis of sub-calcaneal heel spurs (enthesophytes) in cadavers and observed that, contrary to popular belief, these cannot be interpreted as “traction spurs” as they do not form within the plantar fascia itself, but represent a response to mechanical stress due to changes in loading patterns. Following this view, Shaibani *et al*. (1993) had already observed the presence of enthesophytes at the Achilles tendon insertion in the calcaneus, in the area of the plantar fascia, and on the patella and iliac crest in skeletons from the Hamann-Todd collection (described above). The absence of the effect of underlying forms of osteoarthritis, spondyloarthropathy, calcium pyrophosphate deposition disease or DISH, lead the authors to suggest that enthesophyte formation responded to mechanical factors.

However, according to the data obtained by Kalichman *et al.* (2007) from hand radiographs of 424 nuclear families from Russia, enthesophyte formation can result from a combination of physical load and genetic predisposition. However, additional studies are needed to evaluate if the genetic component is restricted only to the hand or may affect multiple sites in the body.

The scarcity of clinical evidence supporting activity-related enthesophyte formation has been overshadowed by research within the bioarchaeological field. Bioarchaeologists have been more easily convinced by the activity-related aetiological factor behind the formation of enthesophytes. According to Kennedy (1989), Hawkey and Merbs (1995), Steen and Lane (1998) and Larsen (2002) it is assumed that performing repetitive tasks over a long period of time, and putting continual mechanical stress on a muscle or group of muscles during a lifetime by muscular tension and contraction, can lead to bone hypertrophy and the formation of enthesophytes. On the other hand, increasing scepticism on how good enthesophytes are as indicators of past activities has been consistently emphasised by Jurmain (1999:145) who criticised the assumption that enthesophytes can be correlated with activity because these markers are multiple in aetiology.

In summary, as reviewed in this section, there are a number of disorders that produce enthesophytes. Unlike in the clinical field, bioarchaeologists may work with skeletons that are poorly preserved which can represent a challenge to clearly differentiate these conditions. In addition to this, it has been observed that there are significant variations between attachments with regard to the impact of mechanical and developmental factors on the occurrence of enthesophytes (Benjamin *et al.*, 1992; Kumai and Benjamin, 2002). Consequently, if enthesophytes do not develop through the same mechanism or in response to the same stimuli, as observed for instance for the tendons of *M. brachialis*, *M. biceps* and *M. triceps* (Benjamin *et al.*, 1992), then probably the best analytical approach would be to analyse each enthesophyte individually.

2.1.5 Symptoms

The clinical evidence suggests a disparity regarding the symptoms of enthesophytes experienced by different people. For instance, Amaravati *et al.* (2005) reported enthesophytes on the superior and inferior surfaces of the calcaneus of unusually large dimensions. The patient had suffered pain in the right ankle for more than 40 years. Similarly Yu *et al*. (1995) conducted a study on nine athletes who underwent surgery for chronic patellar tendinitis and found a correlation between the duration of symptoms (knee pain, swelling and limitation of motion), the resonance imaging and the pathological findings. Slobodin *et al*. (2007) reported two patients with symptoms of bilateral plantar fasciitis and bilateral tibialis posterior tendonitis, along with bilateral entheseal calcification of both shoulder and pelvis. Both complained of bilateral foot pain and from pain in both shoulders and pelvis. In a different example, a patient seen by Varghese *et al*. (2006) with tendinitis on the patella denied any long-term symptoms. The condition was diagnosed only one week after sudden knee pain following an accident while walking, but the presence of “whiskers” of calcification on the patella suggested a chronic enthesopathy.

According to Jurmain (1999:143), one of the reasons why enthesophytes have not been seriously addressed by clinicians is because they rarely produce any distinctive symptoms in patients. Furthermore, it should not be forgotten that the number of possible causes of enthesophyte formation are many and that symptoms vary according to each patient and each muscle or tendon attachment. Nevertheless, whenever the symptoms are evident, the common complaints are stiffness and pain as well as swelling and reduction of mobility of the area affected (Yu *et al*., 1995; Resnick, 2002a).

2.1.6 Enthesophytes and bioarchaeology

The study of enthesophytes to reconstruct activity in archaeology has gained impetus only within the past three decades (Kennedy, 1989) and particularly after a symposium held in 1997 entitled "Activity patterns and musculoskeletal stress markers: An integrative approach to bioarchaeological questions" in St Louis, Missouri at the 66th Annual Meeting of the American Association of Physical Anthropologists. Over the years, an increasing number of papers have been published in the bioarchaeological literature with behavioural interpretations made from solitary and multiple groups of enthesophytes. On the other hand, the scepticism about these markers as reliable osteological features to predict activity has been consistently manifested by Jurmain (1999:150) and more recently by Jurmain and Roberts (2008) and Alves Cardoso and Henderson (2010). In view of the increasing concern regarding the absence of scientific rigor and standards of verification of enthesophytes in bioarchaeological studies, a group of scholars organised the first workshop in musculoskeletal stress markers (MSM) at the University of Coimbra (Portugal) in July 2009. With the aim of developing standardised recording systems for the recording and interpretation of enthesophytes, this workshop set up the basis for future meetings and more rigorous analysis (website http://www.uc.pt/en/cia/people/WinMSM).

(i) Enthesophytes and physical activity/occupation

The importance of studying enthesophytes in bioarchaeology lies in their potential value for addressing hypotheses generated by archaeological data (Hawkey and Merbs, 1995; Peterson, 1998), and to support or reject information about the past provided by other sciences such as ethnography and history (Steen and Lane, 1998).

In this context, enthesophytes have been intensively used to infer patterns of physical activity in prehistoric and historical populations. For instance, Kennedy (1989) reviewed 140 such publications linking work-related activities to individual muscle insertions. One particular example is enthesophyte formation at the *M supinator* attachment in the ulna (Fig 4) where the following five examples of published research depict how interpretations of enthesophytes at a single muscle attachment can lead to so many different behavioural interpretations.

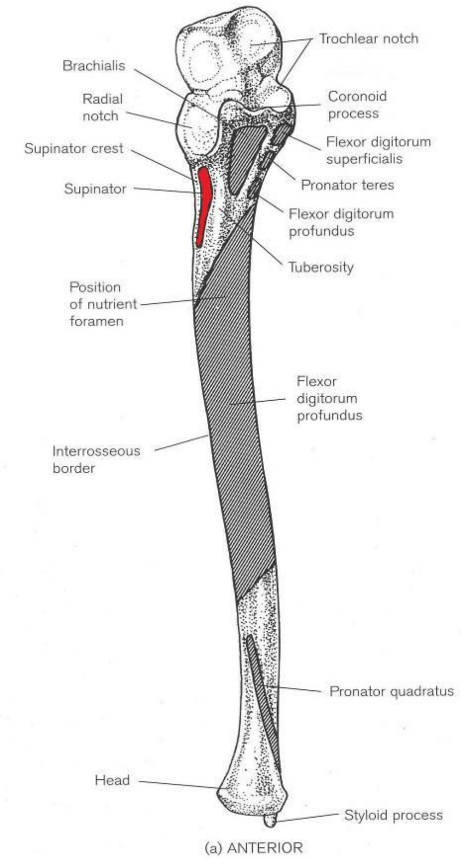


Figure 4: Right ulna showing in red the insertion for *M. supinator*. Modified from Scheuer and Black (2004)

Kennedy (1983) worked with Pleistocene archaeological samples of hunters-gatherers from India and noted that only adult male individuals showed hypertrophy of the ulnar crest to which the *M. supinator* attaches. He correlated this finding with some of the assumed habitual activities performed by hunter-gatherers such as throwing spears, atlatls, boomerangs or similar missile weapons. Hawkey and Merbs (1995) observed that among a number of other muscle insertions, the presence of *M. supinator* among ancient Hudson Bay Eskimos was consistent with females preparing materials for clothing, or rowing a boat, paddling a kayak, and with launching a harpoon in males. In another study carried out by Owsley *et al*. (1987) of an historical cemetery of an urban slave population from New Orleans (USA), the authors found similar hypertrophy of the supinator crest in the ulna. Bone hypertrophy was also found at other muscle insertions such as *M. deltoideus* (humerus), *M. biceps brachialis* (radius) and *M. triceps brachialis* (ulna), which they attributed to a very high level of physical activity and occupational stress probably associated with slavery. Kelley and Angel (1987) worked on 120 skeletons from different slave cemeteries from Maryland, Virginia and the Carolinas (USA) and they also found hypertrophy of the supinator crest. Along with other comparable muscle attachments such as *M. deltoid*, *M. pectoralis*, and *M. teres* and they attributed these muscle expressions to lifting heavy objects, throwing, jack-hammering or those activities required for certain crafts. Finally, another example that continues with the line of attempting to understand activities associated with American slavery is that of Angel *et al*. (1987). They analysed 75 individuals, who were buried in the 19th century First African Baptist church cemetery from Philadelphia (USA). Enthesophytes of the arm and forearm analysed were those associated with *M. deltoid*, *M. pectoralis* (humerus) as well as *M. supinator* (ulna), which they correlated with using axes and lifting and lowering weights.

With regards to the lower limbs, Oates *et al.* (2008) analysed the remains of an incomplete skeleton dated to BC 3000 found at the city of Nagar, today Tell Brak in north-eastern Syria. The authors analysed the muscle insertions of the *M. gluteus maximus* of both femora, the *M. vastus mediales* at the patellae, the insertion of the Achilles tendon to the calcanei as well as the muscle attachments on the toes of both foot. On the basis of this analysis Oates *et al.* (2008) suggested that this skeleton might have represented that of a specialist acrobat or juggler. The muscles of the thigh that straighten the knee and the trunk in most forms of jumping, and the harmstring muscles, as indicated by the prominent soleal line in the tibiae would have allowed spring-like action of the legs. In addition, the authors used evidence from cuneiform texts and seal impressions recovered from the buildings to support the existence of these professionals among the ancient citizens of Tell Brak. Jurmain and Roberts (2008) criticised this approach for the lack of correlation of activity with distinct morphological bone changes. Molleson (2008) responded to this critique acknowledging the difficulties and limitations of such approach, and recognising that other physical activities could have contributed to a similar pattern of morphological change. However, the author did not underestimate the potential value of using enthesophytes to address physical activities and occupations.

As mentioned above, this is just one of the many examples where enthesophytes have been used to infer specific patterns of activity. This kind of interpretative approach has been deeply criticised by Robert Jurmain (1999) and more recently by Jurmain and Roberts (2008) and Alves Cardoso and Henderson (2010). According to Jurmain

(1999:149), interpreting activities in past populations through the analysis of a single or a particular set of muscle attachments is no longer appropriate. The great majority of bioarchaeologists are also becoming aware of the potential pitfalls in relating enthesophytes with a specific activity as the skeleton is subjected to a variety of activities performed at different periods throughout a person's life (Kennedy, 1998; Robb, 1998 and Lovell and Dublenko, 1999). Stirland (1998) has also pointed to the fact that muscles do not work alone but in groups and synergistically (in unison) making it extremely difficult to evaluate specific activities through changes found at individual muscles attachments. Even in skeletal collections with known occupation such as that analysed by Alves Cardoso and Henderson (2010) dated to late 19th and early 20th centuries in Portugal, the authors observed that occupation appeared not to be a major contributing factor to enthesophytes formation of the humerus. Instead, ageing was a key factor in their presence, thus questioning physical activity as the responsible aetiological factor and also their reliability as skeletal markers of activity.

Enthesophytes have also been used to answer specific questions in bioarchaeology regarding sexual division of labour and patterns of handedness and asymmetry. In the former group, Robb (1998) analysed a set of 18 upper and lower limb enthesophytes from an Italian Iron Age cemetery of Pontecagnano, and found that males exhibited greater muscle marking than females at all muscle sites. Similarly, Steen and Lane (1998) compared enthesophytes of the upper limb in two Alaskan Eskimo populations and found that sex-related differences in the expression of these markers were consistent with those described by ethnographic accounts of activity.

With regard to patterns of handedness and asymmetrical enthesophyte formation, Molleson (1989), Wilczak (1998), Peterson (1998, 2002) and al-Oumaoui *et al.* (2004) explored the degree of lateralisation in different groups of human remains by comparing a number of right and left upper limb enthesophytes. Molleson (1989) found a high degree of symmetry among a sample of Mesolithic skeletons from Syria, as did Wilczak (1998) in numerous prehistoric and historic populations from the USA. On the other hand, significant right arm dominance was found by al-Oumaoui *et al.* (2004) in five skeletal samples from Spain and by Peterson (1998, 2002) in Natufian (12500-10000 BP) skeletons from sites in Jordan and Palestine.

Other studies using enthesophytes have emphasised temporal changes in activities. For instance, Chapman (1997) observed that a group of 27 upper limb enthesophytes in an Amerindian population from Pecos Pueblo, New Mexico (USA) demonstrated a statistically significant difference in frequency between pre and post Spanish contact, suggesting intensification of daily activities post contact.

Furthermore, enthesophytes have been also used to diagnose several diseases that lead to their formation such as DISH and other spondyloarthropathies (Arriaza, 1993), to investigate postural or locomotor abnormalities due to anomalies in the musculoskeletal system (Mariotti *et al.*, 2004), and to reconstruct disability and compassion in the skeletal record (Hawkey, 1998).

In summary, as discussed earlier, interpreting physical activity from single muscle markers is no longer acceptable in bioarchaeology. Instead, it has been suggested that enthesophytes are reliable sources of information to reconstruct activity when general patterns of "moderate" or "light" activity are described (Molnar, 2006). Furthermore, and as reviewed in section 2.1.4, entheseal development can be triggered by a variety of factors. Interpreting these osseous manifestations only as indicators of physical activity is no longer defensible as the etiological factors involved in enthesophyte appearance are multiple and complex (Jurmain, 1999:142-149). However, the possibility of controlling for the many variables involved in the expression of enthesophytes is not always possible to achieve in bioarchaeology.

2.1.7 Limitations and future research

Despite recent attempts to create a standardised method for scoring the degree of development of enthesophytes (Mariotti *et al*., 2004; Henderson and Gallant, 2007; Viola *et al*., 2007), most researchers recognise that the absence of objective standards for recording and interpreting enthesophytes and determining their specific aetiology is the major methodological weakness of the field and the most significant limitation for future comparative studies (Robb, 1998; Kennedy, 1998; Stirland, 1998; Steen and Lane, 1998).

Future directions for the development of this field will have to consider independent verification from controlled clinical data where physical activity is a known factor for enthesophyte formation (Jurmain, 1999:159). Although this may sound easy, the clinical literature does not always provide this information as clinicians are more interested in other aspects of these conditions rather than the aetiological factors that have triggered them.

Lastly, increased collaborative studies between bioarchaeologists and clinicians such as that seen in Rogers *et al.* (1997) can lead to more reliable interpretations and conclusions (Jurmain, 1999:163).

2.2 Osteoarthritis

The information discussed in this section is primarily focused on the clinical aspects of osteoarthritis (OA), paying special attention to the numerous variables involved in its expression in humans. In light of this information, the bioarchaeological evidence is reviewed according to the most relevant and significant topics addressed, such as changes in OA with subsistence economy, social status, and physical activity and occupation. Whenever possible and available, information was derived from studies carried out on other Amerindian populations. Finally, limitations and future considerations are summarised.

2.2.1 Definition

OA is the most common degenerative condition encountered in orthopaedic practice and certainly the most common condition affecting humans worldwide according to Bullough (2004a). Osteoarthritis is a non-inflammatory disorder despite it literally meaning inflammatory, unlike many forms of arthritis.

OA affects the diarthrodial joints of the skeleton producing an alteration of the normal joint anatomy (Coote and Haslam, 2004; Bullough, 2004a). Diarthrodial joints (also called synovial joints) are the freely movable joints of all major articular surfaces of the body such as those of the upper and lower limbs, hands and feet. The bones of these joints are covered with hyaline articular cartilage, within a joint cavity, and lined with synovial membrane. This membrane secretes the synovial fluid, which helps lubricate the articular surfaces and reduce friction (Fig 5) (Drake *et al*., 2010). For examples of OA in bone see Figs 3.24 – 3.27.

2.2.2 Terminology and classification

The nomenclature of OA has changed over time. According to Resnick (2002d) there is not a single term which is universally accepted. For instance, for a number of years OA was widely known as degenerative joint disease or simply DJD, but a variety of other terms such as degenerative arthrosis, degenerative arthritis or osteoarthrosis are still commonly found in the clinical literature as descriptors for OA (Resnick, 2002d). For the remainder of this section and for the purpose of this study the term chosen to describe the condition will be osteoarthritis as this is the most commonly used term in clinical and bioarchaeological studies.

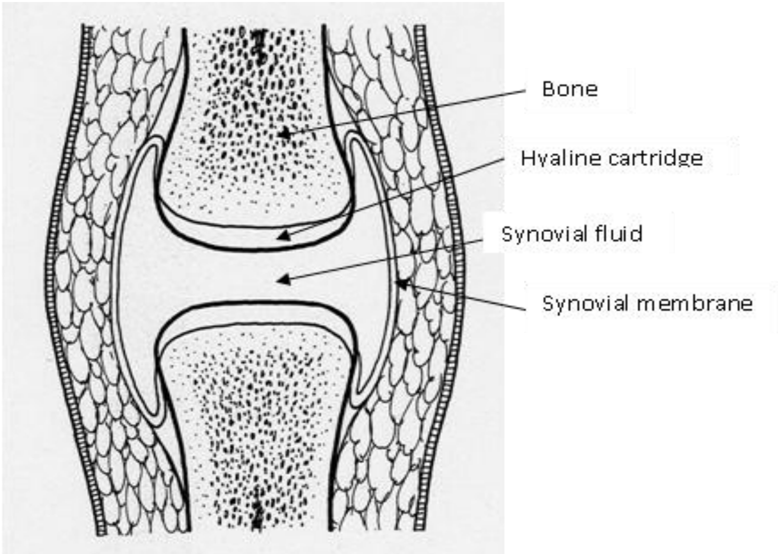


Figure 5: A typical synovial joint (Modified from Resnick, 2002)

The number of classifications of OA is vast. However, most clinicians agree on dividing OA into primary and secondary, former being the idiopathic in aetiology and the latter resulting secondarily to a traumatic event to the joint (Coote and Haslam, 2004). Secondary OA can also occur following a pre-existing affliction like any inflammatory arthropathy such as septic arthritis, or be subsequent to metabolic or endocrine problems such as diabetes mellitus, hypothyroidism or acromegaly. Osteoarthritis can also appear following inherited malformations such as congenital dislocation of the hip, epiphyseal dysplasia or it may even be associated with other seronegative spondyloarthropathies (Cooper, 1998). Other classifications of OA are based on the types of joint affected, for example the hand: interphalangeal joint OA, patello-femoral OA in the knee joint etc., or on the basis of the presence of a specific pathological change such as in erosive OA, inflammatory OA or destructive OA (Cooper, 1998). Other classifications emphasise the number of joints affected. For instance, polyarticular (generalised), as opposed to monoarticular, OA describes when at least three or more joint areas are involved (Cooper, 1998).

2.2.3 Diagnostic criteria

In the clinical field, OA is diagnosed with radiographs if there is narrowing of the space between the joint surfaces, representing the loss of articular cartilage. The complete erosion of the cartilage can lead to exposure of the subchondral bone and sometimes the observation of subchondral cysts, observable in the bone underneath the bone surface (Bullough, 2004a). In weight-bearing joints, further bone to bone contact and friction leads to *eburnation* (from the Latin *eburnea*, meaning ivory), which manifests as a polished and sclerotic bone (Bullough, 2004a) (Fig 3.25). If the polishing persists in the joint surface, eventually the bone becomes grooved and ridged in a parallel fashion according to the direction of the movement. This is particularly evident in hinge joints such as the knee and elbow. New bone formation in the form of *osteophytes* is also a feature of OA, usually appearing around the joint margins as well as on the joint surface. According to Bullough (2004a) osteophytes (Fig 3.26) represent an attempt to repair the loss of cartilage by strengthening the joint.

2.2.4 Epidemiology

(i) Prevalence

The prevalence of OA in populations varies depending on which joint is analysed, the sex and age of the patient. Table 1 summarises the prevalence rates for OA found by three different authors in the three most studied joints of the human body. These studies were conducted in France (Rossignol *et al*., 2005), Norway (Grotle *et al*., 2008) and Greece (Andrianakos *et al.*, 2006) with patients of Caucasian ancestry aged 20-80.

Joint	All	Men	Women	Reference
Knee	59.3% (1680/2834)	63.9% (1031/1615)	53.3% (649/1219)	Rossignol *et al.* 2005
Hip	31.8% (901/2834)	35.4% (571/1615)	27.0% (329/1219)	
Hand	27.4% (776/2834)	15.8% (255/1615)	42.7% (520/1219)	
Knee	6.8% (114/1675)	6.1% (45/732)	7.3% (69/943)	Grotle *et al*. 2008
Hip	4.9% (83/1675)	3.8% (28/732)	5.8% (55/943)	
Hand	4.2% (71/1675)	2.4% (18/732)	5.6% (53/943)	
Knee	6.0% (524/8740)	3.2% (136/4269)	8.7% (388/4471)	Andrianakos *et al*. 2006
Hip	0.9% (78/8740)	0.3% (12/4269)	1.5% (67/4471)	
Hand	2.0% (174/8740)	0.6% (25/4269)	3.4% (152/4471)	

Table 1: Crude prevalence rates of knee, hip and OA reported by clinicians

Differences in prevalence rates between these studies are probably due to differences in methodological analysis. Rossignol *et al.* (2005) diagnosed OA on the basis of radiographs regardless of whether patients were symptomatic or not, thus giving the highest prevalences among the three studies. Grotle *et al.*'s (2008) study was not based on radiographic evidence but on a self-reported questionnaire aimed at reporting the increment in prevalence of OA after a 10 year follow up study (from 1994 to 2004). The study of Andrianakos *et al*. (2006) considered the prevalence of symptomatic patients only.

Despite the variation in prevalence rates found by these three studies, the knee appears to be the weight bearing joint most affected in both sexes. Comparisons between knee and hip OA among the sexes revealed more inconsistent results, although the hand is the non-weight bearing joint of the upper limb more commonly affected in women by two to three times more than men. Occupations in which females are more engaged than men, such as those in the clothing sector, bakers and hairdressers, place a higher risk of disabling OA of the hand due to exposure to repetitive movements according to Rossignol *et al.* (2005).

(ii) Osteoarthritis and age

The onset age of OA ranges from between 50 and 60 years and progressive destruction of the hyaline cartilage occurs towards the 7^{th} and 8^{th} decade of life. However, a direct relationship cannot always be established as, according to Bullough (2004a), many joints can remain unaffected in very old individuals. The knees and the hips, which are the largest joints and those with the greatest exposure to weight bearing and trauma, are particularly predisposed to OA although all major synovial joints can be affected. For instance, a study conducted by Jones *et al.* (2002) of hand OA among 522 Caucasian patients revealed that increasing age was significantly associated with an increase in frequency in both sexes. In line with this study, Andrianakos *et al.* (2006) analysed the prevalence of knee, hand and hip OA in 8,740 patients of both sexes and found that the condition increased significantly with age up to the last age group (≥ 80 yrs) where the condition decreased in prevalence, although this was not statistically significant.

(iii) Osteoarthritis and sex

Clinical literature suggests that men tend to be more affected by the condition up to the age of about 50-55 years, but this situation tends to reverse in older age groups as women are more affected with polyarticular (generalised) OA particularly those of the hand. For instance, in weight bearing joints, a study conducted by Srikanth *et al*. (2005) revealed that females were more affected by OA of the knee than males, particularly after the age of 55 and males were more at risk of cervical OA, especially when younger than 55 years. No sex differences were found in the prevalence of hip OA. In line with these results, Andrianakos *et al.* (2006) observed that females aged ≥ 50 years were positively associated with knee, hand and hip OA.

In non weight bearing joints, typical examples of polyarticular hand OA are the Heberden's nodes that affect the distal interphalangeal joints of the hand producing a lateral deviation of the fingers. Marked sexual differences have been found by Jones *et al.* (2002) who conducted a cross sectional study to analyse the association between sex and hand OA and found that the condition was more common and more severe in women for all categories. Similar results were found by Grotle *et al.* (2008) who performed a 10 years follow-up study and found that hand OA was significantly higher among women compared to men although no significant differences between genders were found in the prevalence of hip and knee OA. According to Resnick (2002d) the reasons for these male-female differences in the distribution and patterning of OA are still unresolved.

(iv) Aetiology

In broad terms, the first pathological change seen in OA is degradation of the hyaline cartilage. The causative phenomena behind this degradation cannot be explained by one factor and therefore the majority of clinicians agree with the idea that OA is a multifactorial condition because of the number of factors found related to its presence (Coote and Haslam, 2004; Bullough, 2004a). A combination of intrinsic factors inherent in hyaline cartilage and any structure that makes up the joint, as well as extrinsic factors including age, sex, hormonal changes, obesity, genetic predisposition, ethnicity, mechanical factors, physical activity, and occupation are all involved in its aetiology.

(a) Age

Osteoarthritis is positively correlated with increased age and therefore seen as a strong risk factor for the condition (Coote and Haslam, 2004). Many studies support this premise; for example, ageing has been significantly associated with hand OA (Jones *et al*., 2002; Solovieva *et al*., 2005), and knee, hip and hand OA (Andrianakos *et al*., 2006). Longitudinal studies such as that carried out by Grotle *et al.* (2008) also confirm this suggestion as a 10 year follow-up study showed that healthy patients developed OA in the hips, the knees and the hands as they grew older.

(b) Hormonal changes

There is an increasing body of evidence suggesting that OA may be hormonally sensitive. For instance, hormonal changes occurring in women during the menopause are highly correlated with OA, particularly polyarticular OA of the hand, as found by studies conducted by Jones *et al.* (2002), Cooley *et al.* (2003) and Andrianakos *et al.* (2006).

Other forms of hormonal changes such as disturbances in the production of growth hormone have been also associated with several degenerative conditions, including OA. The normal growth of long bones of the skeleton is regulated by the normal functioning of the pituitary gland and the secretion of growth hormone. Abnormally high levels of growth hormone have been shown to alter synovial joints in a study conducted by Denko and Malemud (2005).

(c) Obesity

Obesity is a systemic factor considered a serious threat to load bearing joints such as the knee. For instance, Christensen *et al.* (2005) carried out a study on a group of 80 patients and found that weight loss improved dramatically the function of osteoarthritic knees and reduced associated symptoms. Whereas most studies support this premise, excessive weight does not always correlate with hip OA. For instance, Andrianakos *et al.* (2006) and Vignon *et al.* (2006) found that obesity was associated with symptomatic knee and hip OA among adult individuals, but in a ten year follow-up study Grotle *et al.* (2008) found a significant association between obesity and knee OA but no association between obesity and hip OA.

The analysis of obesity affecting non-weight bearing joints such as those of the hands remains controversial. A number of studies have favoured the premise that the weight bearing effect of obesity is inappropriate to explain hand OA. Such are the conclusions arrived at by Jones *et al*. (2002) who observed that obesity and BMI (Body Mass Index) were not associated with the prevalence and severity of hand OA. Opposite results were found by Grotle *et al.* (2008) who observed a significant association between obesity and hand OA.

(d) Genetics

Genetic factors appear to be strongly linked with the aetiology of OA. Population studies have shown that in non-weight bearing joints polyarticular OA of the hand has a strong genetic predisposition in women. Resnick (2002e) emphasised that this is particularly accentuated in middle-aged women. In old females, hand OA is strongly associated with age whereas in the younger patient a genetic predisposition is suggested (Doherty *et al*., 2000).
Other sources of evidence of a genetic influence for OA come from family studies, twin studies and through examination of rare genetic disorders. Spector and MacGregor (2004) emphasised that affected families tend to show an increasing risk of OA in the hands, knees and hip among relatives. Bullough (2004a) observed that these patients tend to be ten years younger than those whose OA aetiology is idiopathic. Twin studies conducted using radiographs of osteoarthritic hands and knees of women have indicated a clear genetic influence for OA ranging from 39-65%; this suggests a heritability factor of 50 % or more for the condition according to Spector *et al*. (1996).

(e) Climate/weather

Little evidence is published on this topic. Although the weather does not play a direct role in the aetiology of OA, it has been suggested that some meteorological variables can affect the occurrence of pain in osteoarthritic joints. Strusberg *et al.* (2002) and Vergés *et al.* (2004) correlated low temperature with exacerbated OA joint pain. The former authors observed that Argentine patients affected by OA felt more sensitive to pain when there was high atmospheric pressure whereas the latter observed a similar effect among Spanish patients in Barcelona, when there was a low atmospheric pressure. Hawley *et al.* (2001) emphasised that although the weather or season was often suggested by patients as the cause of changes in joint related symptoms, the authors found that this appeared to reflect perception rather than reality, as the symptoms did not correlate with the clinical scores for OA that they measured.

(f) Mechanical factors

It has been suggested that a number of mechanical factors play an important role in the aetiology of OA, including mal-alignment of a joint's articular surfaces, joint incongruity, quadriceps weakness, bone and joint overload or bone and joint unload (intentional deprivation of bone and joints of activity). For instance, Bullough (2004b) observed that disruptions in the architectural features of the joint such as changes in joint congruity can lead to instability, mobility disturbances, further damage to the cartilage and secondary OA. Experimental studies such as that of Herzog and Longino (2007) demonstrated that inducing a weakening of the quadriceps in rabbits can cause loss of muscle mass and changes in functional performance, leading to cartilage degeneration and OA. Similarly, Piscoya *et al*. (2005) carried out an experimental study using porcine cartilage and demonstrated that OA is linked to mechanical stress due to abnormal cartilage compression. Abnormal load in an incongruous unstable joint can also lead to appreciable changes in cartilage thickness and secondary OA, as suggested by Goreham-Voss *et al.* (2007) in a simulation study of ankle joint incongruity. Furthermore, depriving joints and bones of mechanical load and stress by means of disuse, and immobilisation produces deterioration of the mechanical properties of tendons and ligaments and can potentially lead to OA (Yasuda and Hayashi, 1999).

(g) Physical activity and occupation

Of more particular interest to the aims of the present study, is the relationship between OA, physical activity and occupation. Clinical studies have shown that performing demanding physical activities can lead to OA; however, not performing any activity at all can also have similar effects.

For instance, certain professions and physical activities involving manual work are well known in occupational medicine for impacting human health, including the development of OA. A number of studies have emphasised that knee and hip OA is considerably more prevalent amongst farmers and farm workers who engage in lifting and carrying heavy loads with a flexed trunk, as well as digging, shovelling or walking on rough ground, than in other workers engaged in less physically demanding activities (Walker-Bone and Palmer, 2002; Whiting and Zernicke, 2008:141). Mining activities, such as those performed by coal miners, involving kneeling or squatting and lifting heavy weights in these positions are, according to McMillan and Nichols (2005), associated with an increased risk of developing OA of the knee. O'Reilly *et al.* (2000) also found that not only miners, but also carpenters, construction workers and fitters who engage in strenuous work involving knee bending, and possibly heavy lifting, are at a higher risk of sustaining knee OA. Contrary to this opinion, Rossignol *et al.* (2005) found the greatest prevalence of primary OA of the hip, knee and hand among female cleaners, followed in decreasing order by women working in the clothing industry, male construction workers and male agricultural workers. Jobs involving heavy labour appeared to have the earliest onset of osteoarthritis with almost 40% of patients reporting their first symptom before the age of 50 years.

Evidence of OA in non-weight bearing joints such as the those of the upper limbs have shown that manual work using vibrating tools such as pneumatic drills, concrete vibrators, chain saws, grinders, among others, are highly associated with OA of the upper limbs (Hagberg, 2002). Hagberg (2002) suggested that the duration as well as the frequency of exposure to a vibrating tool have a direct impact on development of the disorder. Osteoarthritis of the upper limbs, particularly of the hands and wrist, is also commonly found among musicians and string instrument players more than percussionists, according to Mahendranath (2004). The author found that the left side joints were affected more than the right side, but emphasised that a number of extrinsic factors such as the individual technique for playing and holding the instrument, posture and practice schedule were among predisposing factors. In a similar study, Solovieva *et al.* (2005) compared the presence of hand OA among middle-aged women whose occupations involved different hand loads. Teachers had exhibited a higher prevalence of hand OA compared to dentists despite the joints most commonly affected being the same for both occupations. The authors attributed this prevalence difference to variation in load between the groups.

The influence of manual work in the occurrence of OA cannot be dismissed, nor can the direct and indirect social implications of this phenomenon regarding the costs to public health. The degree of impairment and disability, mobility loss, the loss of productivity, the costs of pension benefits, rehabilitation, compensation, and treatment all represent a national economic burden for numerous western countries (Gupta *et al*., 2005).

In sports medicine the association between sport and OA has not always been clear because of the type of sport assessed, the differences in training (recreational, middle, high), length of practice, intensity, and a history of trauma are all directly related to a risk of OA. For instance, Conaghan (2002) suggested that elite athletes engaged in repetitive high intensity and high impact forces such as long distance running, cross country skiing, wrestling, boxing, weightlifting, throwing, basketball, and hockey among others, presented a high risk for injury related OA. There seems to be little risk associated with moderate levels of sport involvement including recreational sports activities such as running. Vignon *et al.* (2006), observed that sport represents a risk factor for knee and hip OA regardless of whether it was recreational in nature, although the risk correlated with variables such as intensity and duration of exposure to activity, history of trauma and being overweight.

2.2.5 Symptoms

Osteoarthritic symptoms are typically manifested by complaints of pain, stiffness, abnormal swelling and loss of motion, although the lack of correlation between symptoms of OA and radiographic features is also widely recognised (Cooper, 1998; Coote and Haslam, 2004; Bullough, 2004a). Absence of symptoms can be due to a number of reasons including the subjective experience of pain which is unique to each person, as well as genetic predisposition, and socio-cultural environment (Neogi *et al*., 2009). Osteoarthritic symptoms can change from one joint to another depending on the degree of joint mobility and there are a number of conditions that can produce similar symptoms as those manifested by OA (Cooper, 1998).

2.2.6 Osteoarthritis and bioarchaeology

Osteoarthritis is, after dental disease, the most frequent pathological condition present in human skeletal remains (Jurmain, 1990). It is also a relatively easy condition to diagnose by macroscopic inspection and probably the oldest for which there is skeletal evidence (Waldron, 1995; Jurmain, 1999:108). The analysis of OA in bioarchaeology has been used to address a number of topics including changes in subsistence economy, social status, physical activity and occupation.

(i) Osteoarthritis and subsistence economy

During the past three decades OA has been intensively used to assess the impact of changes in economy on the health of populations, such as the transition to agriculture. The book "*Paleopathology at the origins of agriculture*" edited by Cohen and Armelagos (1984) was a good compilation of research on the impact of agriculture on the health of, among others, North American populations at the time of its publication. An updated version of this book, with new studies from all over the world, is that of Cohen and Crane-Kramer (2007) "*Ancient health, skeletal indicators of agricultural and economic intensification*". Here, a number of studies were presented and original data is provided in light of new methodological advances in the field.

The general trend seen in studies presented in these books, and from studies from other sources has shown, with a few exceptions, a decrease in OA with the adoption of the agricultural way of life (Larsen, 1984; Jurmain, 1990; Larsen *et al.*, 2007; Danforth *et al.*, 2007; Rojas-Sepúlveda *et al*., 2008). These authors discussed frequency rates for OA in skeletal series whose subsistence economy was based on hunting, gathering and fishing and agriculture. In general terms, assessment of this economic shift involved comparisons of OA in a similar set of joints from individuals of the same region but different time periods and subsistence economies, although comparisons of prehistoric foragers and farmers from different settings were also performed.

Contrary to these data, Hutchinson *et al.* (2007) analysed skeletal remains from coastal North Carolina (USA) and observed that vertebral OA was present in both foraging and agricultural communities although highly associated with the latter group. Similarly, Marquez Morfín and Storey (2007) worked with skeletal remains belonging to five sites from Mesoamerica. They observed that the percentages of hand, wrist and thoracic vertebral OA were double the frequency in the more densely populated centres, suggesting an increase of the condition with dependence on agricultural products in the diet. Ubelaker and Newson (2002) also found an increase in the prevalence of OA over time when working with 22 samples of human skeletal remains from Ecuador.

In contrast, other studies have not found a correlation of OA with subsistence economy. Such as the case of Bridges (1991a) who compared the presence of OA between groups of hunter-gatherers and agriculturalists from north-western Alabama (USA) and, by analysing a group of appendicular joints for that purpose, found that the prevalence of OA did not differ significantly between the groups.

In summary, from the evidence for OA, there appears to be inconsistent results regarding the prevalence of the condition with the transition to agriculture in North and South American populations. Numerous studies have been carried out to explore the impact on health of Amerindians in the southern hemisphere using skeletal and dental markers other than osteoarthritis. Examples of these are the studies of Standen *et al*. (1995), Ubelaker and Newson (2002) Neves and Wesolowski (2002), Alfonso *et al.*

(2007), Pechenkina *et al.* (2007), Gil *et al.* (2009). Future studies, including this one, will certainly contribute to knowledge of this condition and assess whether the temporal trend observed with skeletal remains from the north of the continent can also be extended to South America.

(ii) Osteoarthritis and social status

Although not always so intensively studied as changes in economy, OA has also been used to assess hierarchy and social status differences. A few examples of studies carried out on Amerindian populations and also with European assemblages will be briefly summarised here.

In the Americas, Mayes and Barber (2008) studied the skeleton of a high status individual, a male aged 15-17 years and dating to 100-250 AD buried in a cemetery at Yagüe located in the lower Río Verde Valley in Oaxaca, Mexico. This individual was found buried with a plaster-backed pyrite mirror and an incised flute made from a deer femur, which lead the authors to suggest that this individual had a “special” status. Comparison of this individual with other male “commoners” of the same age indicated that the skeleton did not display signs of OA and therefore Mayes and Barber (2008) suggested that he did not engage in the kinds of physical labour that marked the skeletons of others. However, the question remains, if this individual had special status, why was he buried along with “commoners”? This individual also showed, along with other male “commoners”, a number of dental indicators of stress at weaning. Hence the only difference between this individual and the “commoners” was the lack of OA and, as previously discussed, this skeletal indicator should not be used in isolation to investigate status as other aetiological factors, apart from physical activity, could have played a role.

In the south-central Andean coast of Peru, Wise *et al.* (1994) analysed the skeleton of a 45-50 year old man who dated to the Late Archaic period (ca. 3000-1000 BC). This individual was buried in a shallow circular pit along with an unusual collection of bone and stone artefacts, and different types of textiles. Observation of the elbow joints, the joints of the thoracic vertebrae and of the ribs indicated little osteoarthritic changes given his age. The author concluded that, in comparison with other similar burials belonging to this period, this individual was probably of special status although additional comparative data were needed.

Of more particular interest due to proximity of the skeletal samples analysed to those of this study are the data obtained by Allison (1984:525-7) from skeletal remains dating to 1000 AD from the Maitas-Chiribaya culture of Arica, northern Chile. On the presence of ornaments, loincloths and other material utensils found in the funerary context, the author differentiated three classes of people: male shamans, and commoner males and females. The former group exhibited the lowest prevalence of cervical and lumbar OA compared to the commoner males and females. The author attributed these social differences to the advent of agriculture that benefited a minority, the elite shamans, at the expense of the health of the bulk of the population, i.e. the commoners did the work.

In the Old World, Groves (2006) analysed skeletons from four early medieval populations from north-east England with the objective of examining the relationship between social status and a group of markers of physical activity, including OA. On the basis of artefact groups present in the graves, the author suggested that the level of activity undertaken during life may have been associated with social status. Knüsel *et al*. (1997) examined skeletal remains of adult males from a late medieval monastic cemetery from York (England). They were sub-divided into canons (ecclesiastics with a more sedentary lifestyle), lay individuals (who contributed to the workforce) and high status individuals (of non-ecclesiastic status). The authors found no statistical difference in the patterning of spinal OA among three subsets of skeletons. They concluded that, as OA of the intervertebral and apophyseal joints is consistent with mechanical forces associated with bipedalism, the vertebral column is not a suitable structure to study activity-related OA and therefore infer social status.

To conclude, despite the limited information provided by these examples, it is suggested that if OA relates to social status then this is because there may be a degree of correlation with activity level but also with ageing, although more information is needed to reach a valid conclusion.

(iii) Osteoarthritis and physical activity/occupation

The interest in linking OA with specific activities or occupations relies on the assumption that physically demanding lifestyles and strenuous labour in the past increased the risk of developing OA. The first studies on this topic can be traced back to the early 1970's and, since that time, numerous studies have been produced in the bioarchaeological literature associating specific patterns of OA with identifiable activities. In recent years, researchers have questioned the reliability and potential of using OA as an indicator of activity due to its multifactorial aetiology. Jurmain (1978; 1990) was one of those who in previous years believed in the potential of the condition as a predictor of behaviour in skeletal remains, but gradual disbelief led him and others to sustain a less optimistic approach. In 1999 Jurmain emphasised that, due to the multifactorial nature of OA, mechanical factors play only a part in its development along with other factors. Furthermore, ethnographical evidence to support skeletal findings does not always provide precise information on how often, or for how long, the activities were performed by the individual. Other data such as age of onset of mechanical stress, duration or repetitiveness is not even documented, making any attempt to infer general or even specific patterns of activities unsupportable (Jurmain, 1999:138-9). To conclude, the author stressed that the link between OA and activity cannot be described as a straightforward relationship nor can the level or type of activity performed by the individual.

Some of the early studies illustrating the identification of OA related activities will be briefly summarised. In the Americas, one of the pioneering works in this field was that of Merbs (1983). He worked with a Canadian Inuit population and correlated OA found in the shoulder, elbow, wrist, hand, spine, ribs, hip, knee, ankle, foot and temporo-mandibular joints with specific activities identified from ethnographic sources. To mention a few examples, activities involving softening skins and boots with the teeth were, according to the author, more likely to be manifested by degeneration of the temporo-mandibular joint as he observed this pattern, especially among women. Other activities such as sewing, or hammering, flaking, and splitting hard materials such as bone or stone would be more compatible with OA of the hands and fingers. Paddling a kayak and throwing a harpoon or dart were activities responsible for stress on the shoulders, especially the acromio-clavicular joints and the elbows, although the arms, wrists and hands might have also been used.

In line with this study, Lovell and Dublenko (1999), who also worked with skeletal remains of Eskimos, performed similar work in three males and one female. They found evidence for vertebral OA as well as OA in the knee, hip, metatarso-phalangeal and temporo-mandibular joints in the three males, and vertebral OA in the female. They concluded that this patterning might be consistent with lifting, carrying and canoeing (rowing or paddling) by men, as a consequence of the activities performed in the fur trade in Canada during the 19th century. The spinal arthritis in the female was thought to result from practising heavy horticultural activities. Although the authors supported their findings with information provided by historical accounts, caution should be applied regarding the activities and occupations suggested from the archaeological evidence of a very small sample.

Of particular interest to a number of bioarchaeologists have been osteoarthritic changes of the elbow and their association with specific activities such as spear throwing. Angel (1966) was the first to coin the term “atlatl elbow” referring to the osteoarthritic changes found in the elbow of four males and two females from 13 hunter-gatherer skeletons from California (USA). The author interpreted signs of elbow OA as resulting from repeated stressful action during flexion and extension of the elbow, and pronation and supination of the hand and forearm from long-term use of atlatls. Similarly, Merbs (1983) reported the highest prevalence of OA being in the elbow among all joints analysed in his study, indicating that hurling a harpoon or similar projectile were responsible. In two different papers, Jurmain (1978) and Jurmain and Kilgore (1995) compared the presence of elbow OA among three Amerindian populations, Alaskan Eskimos, Pueblo Indians, and Central Californian Indians with a modern sample of white and black Americans. The highest prevalence of elbow OA occurred among the Eskimo which the authors attributed to repetitive arm movements and impulse loading associated with boat rowing, harpooning and lancing or retrieving captured animals, as well as hunting birds with bow and arrows.

In summary, the elbow has been the focus of attention of a large number of studies of OA because of its alleged connection with activities involving throwing, particularly in men. Bridges (1992) discussed the above-mentioned studies and her opinion is worth highlighting here because it best summarises this discussion. The author observed that OA, particularly OA of the elbow, has been linked to a number of specific activities. In cases where historical records can to some extent be used to understand the behaviour of past populations, it might be possible to suggest some degree of connection between the activity and the development of OA. However, the idea of linking OA of the elbow with specific activities is not possible because different activities can produce the same effect on the joint.

In a different line of research, osteoarthritic changes of the cervical vertebrae have been linked to carrying a load on the head supported by a tumpline. A number of studies such as that of Allison (1984), Bridges (1994) and Lovell (1994) have presented this idea. The former author worked with skeletal remains from the Maitas-Chiribaya groups of Northern Chile and observed the presence of cervical OA and its correlation with finding numerous "capachos" or large baskets in the burial sites of the individuals analysed; he suggested that the OA was probably connected to using a tumpline over the forehead. Cervical OA has also been linked to carrying a weight on the head by Lovell (1994), although Bridges (1994) arrived at a similar conclusion from finding a high prevalence of lower back OA in skeletal remains from the Pickwick Basin area of north-western Alabama (USA). The author suggested that these changes were probably attributed to the impact on the spine as a result of the burden of weight bearing through using a tumpline across the forehead or band across the upper chest. In line with these ideas, Sofaer Derevenski (2000) analysed the spine of individuals from the 16th- 19th century site of Ensay, Outer Hebrides (UK) and observed that females exhibited significant bony manifestations of OA in the lumbar region compared with males. These findings supported historical and ethnographical documents on the gendered division of labour. These described how Ensay females carried loads on their backs using large baskets or creels strapped across their chest and shoulders with the weight resting on the pelvis.

Other specific physical activities and occupations have been linked to OA according to the subsistence economy practised. It has been found that the skeletons of hunter-gatherers often exhibit more OA in the upper limbs compared with those of agricultural populations (Larsen, 2002). For instance, a greater prevalence of OA in the joints of the upper limbs is more likely to occur among hunter-gatherer-fishers as these anatomical areas are more involved in activities such as fishing, harpooning, swimming, diving, sailing, and rowing (Bridges, 1991a; Larsen *et al.*, 2002). This has been supported by a number of studies such as that of Scheel-Ybert *et al.* (2008) and Merbs (1983). The former author observed that the "shellmound builders" of Brazil who settled along the 8,000 km of Atlantic Brazilian coast and practised a subsistence economy based on fishing and shellfish gathering, presented a higher prevalence of OA in the upper than in the lower limbs. Similar results were found by Merbs (1983) who observed that appendicular OA was more highly prevalent in the arms (elbow, shoulder and wrist) than the legs of both male and female Eskimos. On the other hand, and contrary to this trend, Walker and Hollimon (1989) worked on skeletons belonging to Amerindians of the Santa Barbara Channel of southern California (USA) and whose subsistence economy was based on marine resources. The authors observed that individuals of both sexes exhibited a higher severity of OA in the joints of the lower limbs (hip, knee, ankle and foot), compared with those of the upper limbs (shoulder, elbow, wrist and hand).

In summary, the bibliographical review carried out by Bridges (1992) on prehistoric osteoarthritis in pre-Columbian America probably represents the best conclusion to this discussion. The author observed that the greatest prevalence of OA in the Americas was reported to be in the knee followed by the elbow. High prevalence rates of knee and elbow OA have been found to affect prehistoric groups whose subsistence economy ranged from hunting and gathering to agriculture and fishing. Thus, there is no correlation of a specific pattern of OA with any particular subsistence economy.

2.2.7 Limitations and future research

The variation in methods used by different researchers to define, diagnose and record OA is the most important limitation to future development of the use of OA in bioarchaeology as a marker of activity. Thus, the abundant examples of studies available in the bioarchaeological literature where the condition is addressed using different methodological approaches result in data that is inappropriate for inter-populational comparison.

Jurmain (1999:139-40) suggested that in order to standardise methods, OA should be diagnosed only with the presence of eburnation, thus contributing to minimising inter- and intra-observer variation. In fact, according to a study conducted by Waldron and Rogers (1991) on inter-observer variation for coding OA, when eburnation was present the diagnosis of OA was more reliable. A recent attempt aimed at providing standard and consistent methodological analysis is the Global History of Health Project (http://global.sbs.ohio-state.edu/) lead by a number of scholars from the Ohio State University (USA). This project has the objective of measuring health as seen in human remains globally by using a number of skeletal markers, including OA. The important fact about this project is that it provides a standard recording method that enables inter- and intra-regional comparisons. If this method was adopted by more bioarchaeologists it perhaps would lead to less inter and intra observer error and therefore better comparisons between studies. Cohen and Crane-Kramer (2007) are more sceptical about the adoption of such standardisation of techniques between bioarchaeologists as this may be impossible to achieve. Instead, they believe that standardisation of methods should be applied on a smaller scale, in other words, by scholar and their research teams working within a defined geographic area, and by doing so, the problems of genetic and environmental differences between populations as well as a greater chance of inter-observer error would be reduced.

Finally, Jurmain (1999:138-9) advised that a close interaction between clinical and bioarchaeological investigations is needed as this is the best way to ensure a better understanding of the skeletal expression of OA.

2.3 Spondylolysis

In this section clinical and bioarchaeological aspects of spondylolysis are reviewed. The epidemiology of this condition includes the variables of sex, age and prevalence calculation, and special attention was given to aetiological factors as these have been the subject of great debate. In the bioarchaeological literature, the valuable contribution of Charles Merbs to the bioarchaeology of spondylolysis is highlighted. The advantage of being able to analyse dry bones in archaeological contexts allowed the author to produce very thorough descriptions of the condition, bringing to attention issues not previously considered by clinicians. For this reason he is cited and acknowledged in both fields. Finally, limitations and future considerations are summarised.

2.3.1 Definition

Spondylolysis derives from the Greek “spondylo” meaning vertebra and “lysis” meaning separation. This is a defect in the neural arches at the pars interarticularis of the (usually lumbar) vertebrae resulting in a separation of the structure into two parts (Kalichman *et al*., 2009), usually through the isthmus located between the superior and inferior articular processes (Figs 6-7). The anterior portion is comprised of the body, pedicles, transverse processes and superior articular facets and the posterior portion consists of the inferior articular facets, laminae and the spinous process. According to Merbs (1989, 1995, 1996a, 2002b) other sites of lysis can also occur in the pedicle or the lamina although this is a less frequent phenomenon.

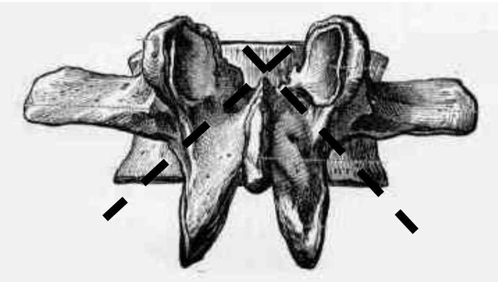


Figure 6 “Classic” spondylolysis showing separation at the pars interarticularis at L5

Figure 7: Az71 T601 showing complete lysis of L5

The typical spondylolytic lesion occurring bilaterally (i.e. complete separation through the pars interarticularis) is frequently followed by spondylolisthesis, the "listhesis" referring to anterior slippage of one vertebra over the unaffected one beneath (Resnick and Goergen, 2002).

2.3.2 Terminology and classification

The term spondylolysis has remained unchanged over time. However, there is a problem that has produced confusion among orthopaedists, anthropologists and other researchers for more than a century. This rests partly with the fact that spondylolysis and spondylolisthesis have often been used interchangeably without a precise description of each condition, and partly with a failure to recognise that both terms are descriptive rather than aetiological (Merbs, 1996a). Furthermore, Merbs (1996a) suggested that the "lysis" part of the term is not appropriate as there are cases where complete separation of the pars interarticularis might not take place. Instead he proposed a more descriptive term such as "spondylo-hyatus" or "spondylo-interruptus" or "separate neural arch" (SNA), making clear that the separation does not need to be complete. However, since these terms were proposed by Merbs (1996a) there appears to be little evidence of their adoption as "spondylolysis" is still used by most bioarchaeologists regardless of whether the lysis of pars interarticularis is complete or not. Finally, Merbs (1996a) poses the question as to whether spondylolysis should be labelled as a pathological condition if this is the result of bipedalism or represents hominid adaptation.

The classification of spondylolysis has also not varied for a number of years. Despite recent efforts (Herman and Pizzutillo, 2005), clinical studies still use the classification proposed by Wiltse e*t al.* (1976) that consists of five basic categories (Table 2).

Type and name	Aetiology
Type (I) Dysplastic	Results from a congenital anomaly of the lumbar spine
Type (II) Isthmic	Takes place in the pars interarticularis and can be subdivided into:
(a) Lytic	(a) Separation of the pars due to a fatigue fracture
(b) Elongated but intact pars	(b) As a consequence of repeated fatigue microfractures that heal but thin out and elongate. If the pars interarticularis separates, the case reclassifies as type (a).
(c) Acute fracture	(c) Appears secondarily to severe trauma.
Type (III) Degenerative	Occurs after a long-standing lumbo-sacral instability that leads to degeneration of the articular facets and consequent forward slipping
Type (IV) Traumatic	Appears following severe trauma in other areas of the neural arch other than the pars
Type (V) Pathological	Due to localised or generalised bone disease, e.g. spondylolysis secondary to syphilitic gummae of the articular process

Table 2: Classification of spondylolysis according to Wiltse *et al.* (1976: 23).

2.3.3 Diagnostic criteria

Spondylolysis is diagnosed clinically through various methods although radiography appears to be the technique most commonly used. According to Pathria (2002), Resnick and Goergen (2002) and Herman and Pizzutillo (2005), if spondylolysis is suspected, then oblique radiographs of the spine as well as projections from different angles provide a reliable aid for confirmation of the diagnosis. On the other hand, when radiographic analysis does not provide conclusive evidence, other alternative imaging techniques including scintigraphy, single photon emission computed tomography (SPECT), computed tomography (CT), magnetic resonance imaging (MRI) and myelography are also utilised (Resnick, 2002d; Herman and Pizutillo, 2005; Kalichman *et al.*, 2009).

The precise diagnosis of spondylolysis sometimes requires more than one form of assessment because clear indications of the condition can be evident with one diagnostic test but negative with a different method. For instance, Ruiz-Cotorro *et al.* (2006) and Takemitsu *et al.* (2006) found that their patients showed no spondylolytic defects on radiographs but were positive with SPECT uptake at the pars interarticularis. Contrary to this, Ruiz-Cotorro *et al.* (2006) discovered that 19 patients showed positive spondylolytic signs in radiographs but were negative with SPECT.

2.3.4 Epidemiology

(i) Prevalence

Large scale population studies suggest that the prevalence rate of spondylolysis in the adult Caucasian population ranges from 4% to 6%. The following studies are summarised in Table 3.

Spondylolysis	General population	
	4.6% (185/4.001)	Sonne-Holm *et al.* (2007)
	6.0% (30/500)	Beutler *et al*. (2003)
	11.5% (21/188)	Kalichman, *et al*. (2009)
	Athlete population	
	14.2% (22/155)	Takemitsu *et al*. (2006)
	8.0% (253/3152)	Soler and Calderón (2000)
	13.5% (473/3505)	Rossi and Dragoni (1994)

Table 3: Prevalence rates of spondylolysis reported by clinicians. Note: prevalences resulted from the number of patients with the condition over the number of patients available for study.

For instance, Sonne-Holm *et al.* (2007) analysed the presence of spondylolysis in a sample of 4,001 individuals (age range 22-93 years) from the Copenhagen City Heart Study, a longitudinal survey based on adult individuals from Österbro in Copenhagen (Denmark). The authors found the condition in 4.6% (185/4,001) of the adult patients. In a 45-year longitudinal study conducted by Beutler *et al.* (2003) the authors assessed the presence of spondylolysis among 500 school children from a northern town in Pennsylvania (USA) and found it to be 4.4% (22/500). Four decades of follow up evaluation revealed eight additional cases, giving a total crude prevalence of 6.0% (30/500). A recent study by Kalichman *et al*. (2009), revealed nearly double the prevalence of previous plain radiograph-based studies (11.5%, 21/188). The authors selected 188 patients for computed tomography (CT) scanning, as an ancillary part of a much larger project involving 3,529 patients aged 40 to 80 years from the Framingham Heart Study in Massachusetts (USA). They explained that the discrepancy between their results and those found by previous authors was due to the use of CT which had allowed better diagnosis than plain radiographs. In summary, this high prevalence suggests that, as discussed in section 2.3.3, the method used to diagnose spondylolysis has a direct impact on the prevalences observed. It could also imply that the condition is under-diagnosed and hence its epidemiology should be reconsidered.

Finally, athletic populations have shown a consistently higher prevalence of spondylolysis compared to non-athletic groups. For instance, prevalence rates for spondylolysis were obtained by Soler and Calderón (2000) from elite Spanish athletes (8.0%, 253/3152), Takemitsu *et al*. (2006) among paediatric athletes from the USA (14.2%, 22/155), and Rossi and Dragoni (1994) among Italian athletes (13.5%, 473/3505). These prevalences seem to vary depending on age, sex and ethnic origin; hence these variables will be discussed in the following sections.

(ii) Spondylolysis and age

With regard to age, spondylolysis is a condition of childhood and early adulthood. Onset age was found to be six years in a population study conducted by Beutler *et al.* (2003), seven years in paediatric patients with lower back pain (Takemitsu *et al.*, 2006), 12 years among young tennis player (Ruiz-Cotorro *et al*. 2006), and 11 years and 13 years among soccer players and cricketers, respectively (Gregory *et al.* 2004).

On the other hand, Merbs (1996a) pointed out that the age of onset for spondylolysis indicated by clinicians might not necessarily reflect the age at which it actually occurred because they only diagnose spondylolysis when the lesion is discovered.
This situation can be obscured even more if no evident symptoms of the condition are present. Furthermore, even when symptoms are evident it is understood that the lesion had been there well before the problem was brought to the attention of the physician (Merbs, 1996a). In addition, radiographs do not always show subtle defects or the early stages of the lesion if they ever show any spondylolytic change at all (Merbs, 1989, 1995), thus not necessarily reflecting the age the lesion commenced. As an example of this, by using single photon emission computed tomography (SPECT), Takemitsu *et al.* (2006) found a younger age of onset for spondylolytic defects in patients complaining of low back pain than previously reported cases diagnosed by radiographs. In conclusion, if the condition could be identified earlier and followed closely, the onset

age would not only be younger but, as Merbs (1995) suggested, the reported present day prevalence and frequency of spondylolysis would be much higher.

With regard to the progression of spondylolysis with age, a number of clinical studies have favoured the premise that spondylolysis is a condition that increases in frequency in adulthood and therefore is not restricted to adolescence. In a 45 year longitudinal study, Beutler *et al.* (2003) observed that 22 patients had spondylolysis at the age of six and that an additional eight cases appeared between the ages of 12 and 25 years, remaining constant thereafter. Similarly, in a cross-sectional survey, Sonne-Holm *et al.* (2007) found that the occurrence of spondylolytic defects was significantly associated with age only at the L4 level in Danish men and women. Kalichman *et al.* (2009) found no difference in prevalence of spondylolysis between different age groups in men, women and the total sample of their cross sectional study. In summary, the premise of spondylolysis increasing with age has not been thoroughly investigated by clinicians and further investigation will be necessary to arrive at a clearer conclusion.

(iii) Spondylolysis and sex

Clinical studies show on a worldwide scale that males are more often affected by spondylolysis than females. The male/female ratio has been reported to be 2:1 according to Beutler *et al*. (2003), and 3:1 according to Kalichman *et al*. (2009), and this relationship is attributed to a number of factors, including pelvic inclination, BMI and lordotic angle (Sonne-Holm *et al*., 2007). In sports medicine, a higher male to female prevalence (between 3:1 and increasing up to 6:1) has been connected with a greater male sporting population (Soler and Calderón, 2000).

(iv) Location of spondylolysis in the spine

Spondylolysis in its classic form is limited to the lumbar region of the spine with L5 being the most affected vertebra (Ruiz-Cotorro *et al*., 2006; Gregory *et al*., 2007). This trend diminishes ascending the vertebral column cranially (Resnick and Goergen, 2002). Sacral spondylolysis is also found although with a much lower frequency

(Whiting and Zernicke, 2008). Atypical spondylolysis is usually found above the lumbar spine. Although rare, the clinical literature provides the majority of the reported examples of cervical and thoracic spondylolytic defects. However, according to Resnick and Goergen (2002), these may be the result of a different pathogenesis, probably attributable to a developmental error (Merbs, 2002b). In fact, cervical spondylolysis appears to be a union failure of chondrification centres, and the aetiology of thoracic spondylolysis seems to be analogous to that of the cervical region (Merbs, 1996a).

Multiple involvement of the spine with spondylolysis is not rare. For instance, Al-Sebai and Al-Khawashki (1999) described a teenage female who, unusually, had a combination of multiple bilateral spondylolysis located at L2, L3 and L4. Chang *et al*. (2001) also analysed the spines of six soldiers who complained of persistent low back pain and found that spondylolysis involved two levels of the spine in five cases and three levels in one. Ruiz-Cotorro *et al.* (2006) worked with 66 young tennis players and found that one of them exhibited bilateral lesions in L5, along with unilateral lesions on the right side of L4 and L3.

(v) Aetiology

The cause of spondylolysis has been the subject of great debate. There are two major contradictory aetiological factors that can explain its presence: hereditability and an acquired stress fracture.

(a) Genetic factors

The clinical literature that supports the hereditary predisposition for spondylolysis is not abundant and in certain cases has produced mixed results. The defenders of this idea believe that spondylolysis represents a congenital malformation, or a developmental ossification failure of the laminae, basing their assumption on family and twin studies.

Two familial studies conducted by Albanese and Pizzutillo (1982) and Young and Koning (2003) have shown that the pars interarticularis defect can affect individuals of the same family. The former authors found evidence of spondylolysis in first degree relatives, including 99 parents and 125 siblings and children, and the latter found spondylolysis at L2 in two identical twins brothers. Despite this evidence, these results should be interpreted with care because there is a tendency to confuse genetic influences with environmental and occupational factors (e.g. the occurrence of spondylolysis in the athletic child of athletic parents). Similarly, questions remain regarding the aetiology of spondylolysis in twin brothers reported by Young and Koning (2003) as they both engaged in strenuous weekly running regimes.

Spondylolysis has also been regarded as an inherited condition because of its association with certain architectural abnormalities of a congenital nature such as spina bifida occulta, transitional vertebrae, lumbarisation or sacralisation. However, the clinical literature has produced mixed results. For instance, Schwartz (2001) reported an individual with spondylolysis and spina bifida occulta in C6. Whereas this example might support the premise that spondylolysis is inherited, “atypical spondylolysis”, usually above the lumbar spine as discussed earlier, might illustrate a different pathogenesis probably attributable to a developmental error (Merbs, 2002b; Resnick and Goergen, 2002). On the other hand, Rosenberg *et al*. (1981) found spina bifida occulta and transitional vertebrae present in 8.4% and 10.9%, respectively, of spines of 143 patients who had never walked. As none of these patients showed evidence of spondylolysis the authors suggested that the condition is more likely to develop as a consequence of ambulatory activities. An association of sacralisation of L5 and multiple involvement of spondylolysis (L2-L3-L4) was also reported by Al-Sebai and Al-Khawashki (1999) in a teenage patient. However, the girl had a familial predisposition in that her mother was found to have spondylolisthesis of L5/S1.

To summarise, if spondylolysis was a congenital condition then some genetic basis should be implied, but demonstrating the presence of a spondylolytic gene that controls the trait is, as yet, far from being achieved. Furthermore, indirect evidence of its aetiology based on its association with other abnormalities of a congenital nature is also far from being proved. On the other hand, it could be argued that there is a genetic influence on the weakness of the pars interarticularis that would predispose certain people to express the abnormality (Merbs, 1989, 1996a; Resnick and Goergen, 2002; Young and Koning, 2003; Roberts and Manchester, 2005:106). Tissue matrix composition (Whiting and Zernicke, 2008:129), an abnormally narrow arch or unusually large vascular foramina (Merbs, 1996a) have been suggested as indicative features of weakness. Certainly, these should be taken into consideration when performing studies aiming to evaluate the aetiological factors for spondylolysis.

(b) Stress fracture

Present day consensus supports the idea that spondylolysis is an acquired traumatic lesion and the consequence of "overuse syndrome" occurring sometime between infancy and early adult life. In the clinical literature it is often discussed under "stress fracture", "fatigue fracture", "cumulative traumatic disorders", "repetitive stress syndromes" or "overuse injuries". This is because lesions of this type result from cumulative micro-fractures at the pars interarticularis region that exceed the capacity of bone repair, thus producing eventual stress fracture (Whiting and Zernicke, 2008:280). A number of variables such as the location, direction, duration and magnitude of the loading, as well as the number of repetitions and also the frequency of load application, can contribute to produce the fracture (Delforge, 2002:150).

There are two basic movements regarded as potentially predisposing to a stress fracture, repetitive spinal flexion and extension (Pećina and Bojanić, 1993:98; Bono, 2004; Whiting and Zernicke (2008:280). More specifically, whereas, Soler and Calderón (2000) and Chosa *et al*. (2004) include torsion to the above mentioned, Jakab (1989) advocates a combination of hyperextension with compression loading as another plausible causative force. Furthermore, Merbs (1996a) points to the fact that excessive load on the articular processes of the lumbar vertebrae can exercise stress on the pars interarticularis due to our bipedal position. As this is not the case in quadrupedal animals, as they do not walk on two legs or sit upright, the author suggests that spondylolysis is unique to humans. Studies performed on patients who have never walked confirm this assumption that spondylolysis represents a fatigue fracture resulting from ambulatory activities (Rosenberg *et al*., 1981).

There are a number physical activities and occupations that required the practice of above-mentioned movements over a long period of time. This is seen especially in young athletes and patients who perform vigorous physical activities at a competitive level. For instance, a comparative study carried out by Soler and Calderón (2000) among elite Spanish athletes found that throwing sports produced the highest percentages of spondylolysis (26.7%) followed by artistic gymnastics (17.0%) and rowing (16.9%). Bono (2004) also found that gymnastics, along with wrestling and diving, produced similarly high rates of spondylolysis. Pećina and Bojanić (1993:98) emphasised that gymnasts, especially females who have been training for a number of years and who belong to the top class of competition, are particularly at risk. This is due to the fact that excessive flexing of the spine, a prerequisite for their training and performance, results in hyperlordosis and increased lumbar retroflexion and consequently injury and low back pain. A similar study of competitive athletes showed that divers (43.1%), wrestlers (29.8%) and weight lifters (22.7%) were severely affected by this condition (Rossi and Dragoni, 1990). Furthermore, spondylolysis has also been identified in the lumbar vertebrae of footballers and cricketers. According to Hardcastle *et al.* (1992) and Gregory *et al.* (2004) unilateral spondylolysis tends to arise more frequently on the opposite side of the bowling arm of the cricketer, which is probably the result of repetitive rotation and/or hyperextension before delivering the ball (Hardcastle *et al*., 1992). Football players instead had a more symmetrical distribution of the lesion according to Gregory *et al*. (2004). Finally, young tennis players can also be added to this long list. The findings of Ruiz-Cotorro *et al*. (2006) indicate that extension with forced rotation during the forehand stroke may be a significant predisposing factor for the condition among this group.

Experimental studies intending to mimic the deformities seen in paediatric cases of spondylolysis, such as those performed on *in vivo* primates (Konz *et al*., 2001) and rats (Sakamaki *et al*., 2003), and through three-dimensional mechanical models (Dietrich and Kurowski, 1985; Chosa *et al*., 2004) or the mathematics of biomechanics (Klemencsics and Kiss, 2001), all reinforce the "traumatic-acquired" over the "genetic origin" aetiology.

To summarise, assuming that physically active individuals such as athletes are more at risk of developing pars interarticularis defects, one would expect them to have a higher prevalence of the lesion compared to the general population. The comparative studies of Rossi and Dragoni, (1990, 1994), Soler and Calderón (2000) Takemitsu *et al.* (2006) between sports people and the general population confirm this idea, and reinforced the suggestion that spondylolysis responds to an acquired rather than a genetic aetiology.

On the other hand, apart from external load, mechanical stress and movement performed, there are other characteristics inherent to human spines such as the dimensions of the vertebrae, predisposition to failure, and resistance to pathological changes that can play an important role in predisposing the bone to fracture (Dietrich and Kurowski, 1985). These all, as a whole, should be taken into consideration when evaluating the possible aetiological factor triggering spondylolysis.

2.3.5 Symptoms

Back pain is the most common complaint in spondylolysis and the main reason that patients seek the help of a doctor (Rossi and Dragoni, 1994; Al-Sebai and Al-Khawashki, 1999; Chang *et al*., 2001; Gregory *et al*., 2004). According to Sponseller (1996) the pain can occur spontaneously at night or be constant and last for several weeks, producing stiffness and motion limitation. It can also produce compression of the spinal cord at the site of the lesion (Pećina and Bojanić, 1993:97; Roberts and Manchester, 2005:57) and/or pressure on the dura mater and cauda equina (Dandy and Edwards, 1998:444). The probability of manifesting subsequent neurological side effects from such compression and obstruction is very high, as indicated in a reported case by Al-Sebai and Al-Khawashki (1999).

2.3.6 Spondylolysis and bioarchaeology

In bioarchaeological contexts, the study of spondylolysis has developed mostly due to the valuable contribution of Charles Merbs (1983, 1989, 1995, 1996a and b, 2001, 2002 a, b) to the bioarchaeology of spondylolysis in general, and to the understanding of its dynamics in ancient Canadian and Alaskan Eskimos in particular. The advantage of being able to analyse dry bones in archaeological contexts allowed Merbs to produce very thorough descriptions of the condition, highlighting issues not previously considered by clinicians. For example there is an absence of any reference to sacral spondylolysis in the clinical literature. According to Merbs (1996b) this could be because the condition has gone unrecognised by clinicians, especially if symptoms are absent, or simply because it is rare in living populations.

Merbs also pioneered the analysis of the developmental stages of the lesion, which had not been explored by previous scholars. According to Merbs (1989, 2002a) the classic example of complete bilateral lysis at the pars interarticularis only represents the final stages of a process that began in adolescence, with an incomplete unilateral stress fracture (either on the right or on the left pars). Progression to bilateral separation, usually by young adulthood, can occur when the opposite intact arch is exposed to abnormal stress. He therefore recognised different types and variants of incomplete and complete spondylolysis. This provided much easier and more practical diagnostic criteria for bioarchaeologists dealing with dry bones than that proposed by Wiltse e*t al.* (1976) for living patients. This is a more straightforward system for diagnosis that could be easily adopted as a new classification system by all bioarchaeologists (summarised in Table 4).

Types	Variants	
1. Incomplete separation	Incomplete unilateral	Incomplete bilateral
2. Complete separation (on just one side)	Complete on one side, incomplete on the other side	Complete on one side, normal on the other side
3. Complete separation (on both sides)	Completely bilateral at pars interarticularis on both sides (classic isthmic)	Completely bilateral at pars on one side, but a pedicle or lamina on the other side

Table 4: Classification of spondylolysis according to Merbs (2002a:161)

Further contributions from Merbs to this field include the analysis of how handedness may be connected to incomplete lysis appearing more often on the right hand side than the left. Despite the fact that incomplete spondylolytic defects have been recognised in the clinical field, its early stages are often not diagnosed and therefore remain ignored. Merbs (1995, 2002a) found an interesting pattern of incomplete separation that usually proceeds inferiorly from the superior margin of the pars interarticularis, superiorly from the inferior margin, or from both pars interarticularis margins simultaneously. As these defect types are more often found on the right hand side of the pars than the left Merbs (1995, 2002a) suggested that this particular trend could be related in some way to activities involving the dominant arm and hand, with forces being somehow transmitted to the lower back.

Lastly, Merbs also contributed to knowledge about the healing of spondylolytic lesions. Little is known about this subject in the clinical field because recording stages of healing in standard radiological examination is not an easy task. In archaeological skeletal samples, Merbs (1995, 1996b) observed that the prevalence of spondylolysis decreased from middle-aged to older adult individuals, and suggested that this could be due to a spontaneous healing process rather than to sample size or preservation. This concept is reinforced by the fact that no ethnographic evidence supports the idea that any artificial form of back immobilisation was practised as a form of therapy among the ancient Canadian Eskimos (Merbs, 1995). Merbs also observed that complete lysis could heal completely as evidenced by the presence of bone callus around the defects. This is particularly common if the condition remained unilateral and severe olisthesis did not occur.

(i) Prevalence

As mentioned earlier, Merbs based his studies almost entirely on skeletal remains of Amerindians from North America, in particular Eskimos from Alaska and Canada. He found very high spondylolytic frequencies in skeletons from these areas, ranging from 20% to 60%. Subsequent studies carried out with vertebral remains of other groups of Eskimos revealed similar prevalence findings (Legge, 2005; Timm, 2008).

All reported bioarchaeological data regarding prevalence rates for these groups or any other group are summarised in Table 5. These are mainly studies carried out by Merbs (1983) with the Sadlermuit from Southampton Island (Canada) and with Inuit skeletons from Alaska and Canada (Merbs, 1996b). In a more recent work, Merbs (2002a) analysed the presence of complete, incomplete, symmetrical and asymmetrical separation at the pars interarticularis in Canadian Inuit skeletons. In a similar study, Merbs (2002b) analysed the spines of Arctic Canadian Inuit skeletons (children through to old adults) from different geographic areas and time periods. Legge (2005) analysed two skeletal collections from Golovin Bay and Nunivak Island (Alaska) and Timm (2008) compared the prevalence of spondylolysis in two Inuit groups from Point Hope (Alaska), the Ipiutak and the Tigarak.

	Prevalence	Vertebra	Group	Reference
Spondylolysis	North American Amerindians			
	True 18.6% (8/43)	L1-L5	Archaic Alabama	Bridges (1989a)
	True 4.2% (16/373)	S1	Eskimos	Merbs (1996b)
	True 64.0% (61/114)	L1-S1	Eskimos	Merbs (2002a)
	True 52.2% (60/115)	L1-S1	Eskimos	Merbs (2002b)
	Crude 22.6% (19/84)	L1-S1	Eskimos	Merbs (1983)
	Crude 54.5% (18/33)	Not specified	Eskimos	Legge (2005)
	Crude 20% (6/30)	Not specified	Eskimos	Timm (2008)
	Crude 55.4% (51/92)	Not specified	Eskimos	Timm (2008)
	Crude 13.0% (64/491)	L1-S1	Pueblo Indians	Merbs (2001)
	South American Amerindians			
	Crude 10.0% (3/30)	L4-L5	Fuegian Indians	Castro and Aspillaga (1991)
	Crude 9.8% (5/51)	Not specified	Chinchorro Indians	Arriaza (1995a)
	Old World			
	Crude 7.9% (29/368)	L3-L6	Medieval (UK)	Stirland (1996)
	Crude 11.9% (24/201)	L1-L6	Medieval (UK)	Mays (2006a)
	Crude 0.7% (1/40)	L1-L6	Medieval (UK)	Mays (2006b)
	Crude 3.7% (8/214)	C4, L2-L5	Romano-British (UK)	Waldron (1991)
	Crude 4.6% (6/110)	C4, L2-L5	Anglo-Saxon (UK)	Waldron (1991)
	Crude 5.1% (32/629)	C4, L2-L5	Medieval (UK)	Waldron (1991)
	Crude 1.4% (10/706)	C4, L2-L5	Victorian (UK)	Waldron (1991)
	Crude 5.1% (32/629)	L2-L6	Medieval (UK)	Fibiger and Knüsel (2005)
	Crude 0.7% (7/968)	L2-L6	Victorian (UK)	Fibiger and Knüsel (2005)
	Crude 1.7% (5/292)	Not specified	Iron Age (UK)	Roberts and Cox (2003:98)
	Crude 2.0% (49/2475)	Not specified	Roman period (UK)	Roberts and Cox (2003:151)
	Crude 2.9% (92/3185)	Not specified	Medieval (UK)	Roberts and Cox (2003:208)
	Crude 15.2% (6/39)	Not specified	Neolithic (Sweden)	Molnar (2006)
	Crude 6.6% (12/181)	L4-L5	Medieval (Slovakia)	Masnicová and Beňuš (2003)

Table 5: True and crude prevalence rates of spondylolysis reported by bioarchaeologists

Note: true prevalence derives from the number of vertebrae affected over the number of vertebrae available for study. Crude prevalence derives from the number of individuals affected with the condition over the number of individuals available for study, regardless of preservation of the spine.

Relatively little is known about the occurrence of spondylolysis in Amerindians from other regions. However, the studies of Bridges (1989a) and Merbs (2001) provide a general insight into the dynamics and nature of this lesion in other prehistoric populations. Bridges analysed the skeletal remains of archaic hunter-gatherers from north-western Alabama, and Merbs (2001) worked with ancient and early historical skeletons from New Mexico Pueblo sites.

Studies of spondylolysis in South American populations are not well documented and for this reason, prevalence rates are not always included in Table 5. The absence of systematic studies of spondylolysis has been attributed to a possible belief that the condition is congenital rather than an acquired pathological condition (Arriaza, 1995a). Alternatively, it could be argued that information exists but it is in the form of unpublished reports, in published reports of low impact or that they are isolated cases which are not worth publishing because they do not provide any palaeoepidemiological significance. One of the pioneering and earliest works in this part of the world is that of Ten Kate (1896). He analysed the spines of skeletons from different Argentinean Indians such as the Fuegians, Pampeanos, Huarpes, Tehuelches and Tobas and found spondylolytic lesions in L4, L5 and S1. Regrettably, Ten Kate did not provide information on how he arrived at a prevalence of 8.8% or how the lesions were distributed according to sex or age. Castro and Aspillaga (1991) studied the lumbar vertebrae of Fuegian Amerindians from Chile and Argentina and reported crude prevalences for the condition (Table 5). In a later paper, Aspillaga *et al.* (2006) also analysed skeletons of Fuegians and compared them with the Chonos who settled the Southern Chilean Patagonia. These authors found defects of pars interarticularis in L4 and L5 and a coincidental prevalence of 25% in both groups, which represents a more elevated rate than that suggested by Ten Kate (1896). Detailed information regarding the method used to calculate this prevalence was not included in the paper; however the authors clarified that the number of vertebrae affected were counted according to the total number of vertebrae available, and then analysed according to which spinal area they belonged to (pers. comm. 2009).

Arriaza (1995a: 69-71) reported the crude prevalence rate for spondylolysis among the Chinchorro people, pre-ceramic fishers who settled along the coast of the Atacama Desert from 7,000 BC to 1,500 BC in Chile (Table 5). Elsewhere in South America, Mendonça de Souza (1992) analysed the spines of 25 skeletons recovered from a rock shelter in Pernambuco (Brazil) dated to the early Holocene (ca. 11.060 BP). She found that 11 of 25 (44.0%) individuals exhibited evidence of vertebral fractures although the distinction between spondylolysis and compression fractures was not provided.

In the Old World, studies of spondylolysis are abundant and particularly in the UK where attempts to reconstruct the nature of spondylolysis seem to be more systematic. Prevalence calculations reviewed in this section, are summarised in Table 5. For instance, Stirland (1996) reported the pattern of spondylolysis among males and females from a medieval cemetery in Norwich, Norfolk (England). Similar studies within this time period were carried out by Mays (2006a, b) on adults and non-adults from Wharram Percy, a rural English medieval site in North Yorkshire. A number of researchers have focused their attention on the diachronic analysis of spondylolysis. For instance, Waldron (1991) calculated crude prevalence rates of spondylolysis from Romano-British to Anglo-Saxon, Medieval and Victorian periods. Fibiger and Knüsel (2005) carried out a similar study on human remains from six different sites in England, representing a variety of social groups that extended from the 5th to the 19th century. Roberts and Cox (2003) also analysed the presence of spondylolysis over time in British populations gathering data from published and unpublished sources. Outside the UK, Molnar (2006) analysed the presence of spondylolysis in skeletons dated to the middle Neolithic from Gotland (Sweden) and Masnicová and Beňuš (2003) reported on spondylolysis in skeletons from two sites in Slovakia dated from the 11th-12th century and the 9th century, respectively.

To summarise, the prevalence of spondylolysis varies widely among populations over time. Attempting to perform inter-population comparisons can be very difficult especially because of differences encountered in the method of calculations of frequency rates. This is a subject discussed further in section 2.3.7. Despite this, a general trend can be drawn from the examples analysed above. Bioarchaeological studies provide higher frequencies of spondylolysis when compared to present day population studies. Merbs (1989) suggested that this is because occupationally related stress in labouring societies of antiquity was greater than it is today. Merbs (1989) also indicated that the analysis of human skeletal remains presents an advantage over clinical studies, due to the fact that identification of defects at the pars interarticularis via radiography, including those in the process of healing (Mays, 1991; Merbs, 1996a, b; Fibiger and Knüsel, 2005), is not always possible in living patients. This in turn leads to an underestimate of the true frequency.

Furthermore, the highest frequencies of spondylolysis appear to be found in ancient Eskimos (Merbs, 1983, 2002a and b) and relatively high frequencies are also found in other Amerindians such as Archaic Indians from Alabama (Bridges, 1989a). Spondylolytic prevalences in British populations are low when compared to those mentioned above, and to other Europeans and modern day athletes. However, as Fibiger and Knüsel (2005) emphasised, this could be due to present day competitive athletes engaging in very high levels of daily training extended over time, a situation that past populations would have rarely encountered.

(ii) Physical activity and occupation

There are two contradictory views with regard to reporting the association of specific physical activities and spondylolysis. On the one hand, some make reference to general patterns of activity, being cautious in not making over simplistic or imaginative assumptions. Alternatively, scholars have also ventured to correlate spondylolysis with more specific physical activities.

Examples of the former group are Fibiger and Knüsel (2005) who recognised that prevalence rates they found in British skeletal populations provided a significant insight into the different levels of strenuous activity in the past. Bridges (1989a) also arrived at a similar conclusion. She stressed that specific activities cannot be assumed from the spondylolytic defects found in prehistoric Indians from Alabama because a number of movements might be connected with their presence. Arriaza (1995a: 69-71) also followed this argument by supporting the general idea that spondylolysis might have been a common ailment of the Chinchorro men who performed physically demanding tasks involving hyperextension of the back. Finally, Stirland (1996) indicated that the occupations of the interred medieval individuals in Norwich, Norfolk (UK), particularly the activities that might have been associated with spondylolysis, should remain speculative. She recognised that this task is one of the major difficulties that bioarchaeologists have to face.

In the second group, Arriaza (1997) inferred that the presence of spondylolysis among the Chamorro people from the Micronesian Island of Guam was due to some of the daily activities they performed such as harpoon fishing, but more importantly to the occasional pulling, lifting and transporting of the heavy “latte” stones that these people used as pillars for their houses. Although this activity was not necessarily performed on a daily basis, the author suggested that either a single violent episode or the sporadic dragging and lifting of these stones would have certainly required hyperextension and plenty of lower back muscle constriction necessary to produce the condition. Aspillaga *et al*. (2006) correlated the presence of spondylolysis among the Chonos and Fuegian Amerindians with activities associated with carrying heavy loads such as hunted dead animals, wood, and canoes, amongst others. Mays (2006a) emphasised that the presence of spondylolysis in a rural English medieval site could be interpreted as the result of strenuous physical labour that agricultural activities involved such as lifting produce, guiding the plough, digging, weeding fields and reaping crops, thus reflecting the physical arduous lifestyle this community had. Furthermore, Merbs (1983) believed that some of the activities that possibly led to the presence of spondylolysis in the Sadlermuit Eskimos from Southampton Island, Canada were weight lifting, wrestling, kayak paddling and harpoon throwing, all very important for young male individuals. However, he cautiously emphasised that any attempt to pin down specific behaviours to this anomaly will likely prove to be a difficult task in these archaeological skeletons.

To summarise, given the broad range of occupations and sports associated with spondylolysis in living groups, trying to attribute any specific activity to prehistoric groups could seem very ambitious. On the other hand, despite numerous occasions where the presence of spondylolysis is supported by ethnohistorical information, the specific activities performed and the real aetiological factors involved in triggering the condition will remain an enigma.

2.3.7 Limitations and future research

The most important limitation in the study of spondylolysis is the method used to calculate prevalence rates as there does not appear to be a recognised and accepted universal method. As an example of this, Fibiger and Knüsel (2005) reported a variation in spondylolytic rates from less than 1% to as much as 12% depending on the method selected, thus demonstrating how sensitive prevalence rates are to different calculations. In conclusion, in order to be able to compare prevalence rates among different populations it is imperative that future research states clearly the method used. Jurmain (1999:229) suggested that accurate prevalence rates should be determined according to the number of complete osseous elements present for observation, rather than according to the total number of individuals analysed, regardless of spinal preservation.

Finally, there is an issue regarding whether partial cracks and incomplete lysis should be considered true spondylolysis and therefore be included in overall prevalence rates. Merbs (1995) suggested that, by doing this, there is a chance of over-diagnosing the condition and therefore unilateral and bilateral prevalences should be recorded separately.

2.4 Os acromiale

In this section clinical and bioarchaeological aspects of os acromiale are reviewed. A number of aspects, including the epidemiology of the condition as well as its aetiology and possible connection with physical activity, are presented in light of the clinical data and from a bioarchaeological perspective.

2.4.1 Definition

Os acromiale is a condition that results from the non-fusion of the acromion of the scapula (Resnick, 2002c) (Fig 8).

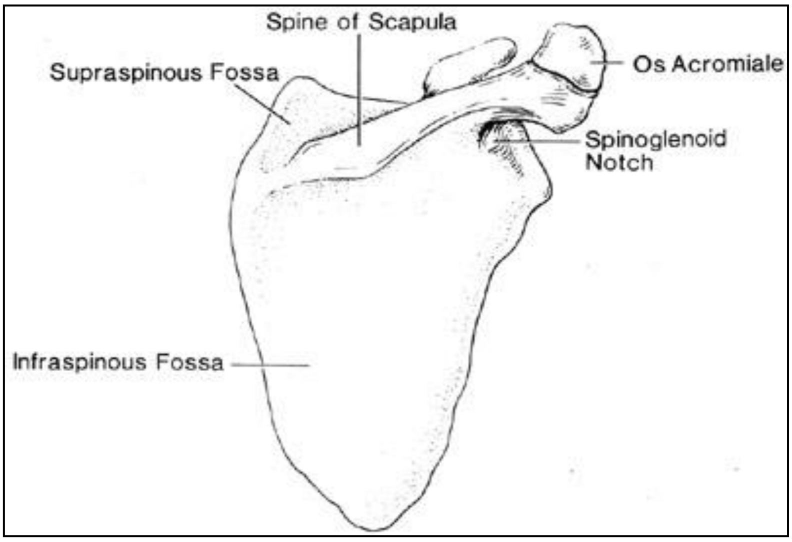


Figure 8: Os acromiale in the right scapula

2.4.2 Terminology and classification

Os acromiale is also described in the literature as os acromial, unfused acromial apophysis, bipartite acromion or meta-acromion. However, the most popular name and the one adopted for the remainder of this discussion is os acromiale.

With a few variants, the modern classification of os acromiale was originally proposed by Liberson (1937) and has persisted in the current orthopaedic literature for more than 70 years. This classification is based on the locations where ossification fusion has failed to occur. To understand this, it is necessary to review the embryological development of the acromion. Scheuer and Black (2004) state that the acromion of the scapula develops ontogenetically from four distinct ossification centres; the pre-acromion; the meso-acromion, the meta-acromion, and the basi-acromion (Fig 9).

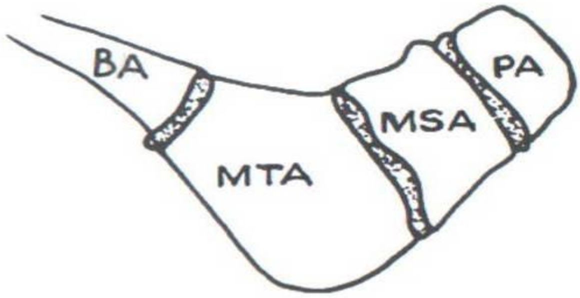


Figure 9: Ossification centres of the acromion of the scapula. Note: PA= pre-acromion, MSA= meso-acromion, MTA= meta-acromion, and BA= basi-acromion (Modified from Edelson *et al*., 1993: 553).

Liberson (1937) only considers the first three listed above, because the basi-acromion is a continuation of the ossification centre for the scapula. Os acromiale has therefore been classified into “type A” which results from the failure of fusion between the meso-acromion and meta-acromion, “type B” failure of fusion between the pre-acromion and meso-acromion and “type C”, failure of fusion between the meta-acromion and basi-acromion. The commonest type appears to be type A followed by type B (Warner *et al.*, 1998; Boehm *et al.*, 2005; Burbank *et al.*, 2007). Type C is rarely seen although it has been reported to be present in the study conducted by Park *et al.* (1994). Recognition of these ossification centres within the acromion and its further classification has led to considerable confusion in the literature, particularly when it comes to defining os acromiale. Some scholars believe that os acromiale should be named as such only when it occurs at the meso and the meta-acromion junction (Scheuer and Black, 2004; Demetracopoulos *et al.*, 2006). On the other hand, Liberson (1937), Gumina *et al.* (2003) and Pagnani *et al.* (2006) suggest that os acromiale should be defined as the failure of any of the three centres to unite with its neighbour, resulting in three possible forms.

With regard to the size or shape of the acromial fragment, no published classification has been found. This is probably because it will depend upon which ossification centre fails to fuse. Although according to Resnick (2002c) the size and shape of the acromial fragment varies, its shape tends to be triangular.

2.4.3 Diagnostic criteria

A number of diagnostic clinical methods have been employed with different degrees of success to detect os acromiale. Initial diagnosis begins with direct examination of the shoulder. Possible signs of the condition involve the presence of discomfort and pain when applying pressure on the acromion, as experienced by patients seen by Peckett *et al.* (2004) and Pagnani *et al.* (2006), as well as tenderness on the acromio-clavicular joint as observed by Demetracopoulos *et al.* (2006). Confirmation of possible signs of os acromiale involves radiographic analysis of the shoulder joint taken at different projections from the arm-pit. However, as these can sometimes introduce an error due to sensitivity in the detection of the condition, other methods such as computed tomography (CT) and magnetic resonance imaging (MRI) have also been reported as being employed to help diagnosis (Park *et al.*, 1994; Pagnani *et al.*, 2006). Os acromiale has been diagnosed accidentally in asymptomatic patients when underarm radiographs were obtained after injuries, as reported by Edelson *et al.* (1993).

Some of the difficulties arising from diagnosing os acromiale are related to the fact that complete fusion of the ossification centres of the acromion does not occur until the age of 25 years. This makes it difficult to differentiate between a persistent unfused acromial apophysis with true os acromiale (Pagnani *et al.*, 2006). Sammarco (2000), who worked on skeletons from the Hamann-Todd collection (described above), also highlighted this observation and warned that careful observation was needed to clearly differentiate os acromiale affecting adult individuals from that commonly found among the younger groups, where the fragment is in the process of fusing.

2.4.4 Epidemiology

(i) Prevalence

In general terms the reported prevalence rate for os acromiale ranges between 1% and 15% of people (Resnick, 2002c; Boehm *et al*., 2005). However, the prevalence of os acromiale varies widely depending on the recording method used. For instance, the number of scapulae affected according to the total number of scapulae observed will differ from the number of patients affected by the condition regardless of whether one or both scapulae are observed. Regretfully, the method used for calculation of os acromiale frequency, which is essential information to understand the epidemiology of the condition, is not always provided in the clinical literature.

A number of studies such as that of Edelson *et al.* (1993), Sammarco (2000), Boehm *et al.* (2005), Burbank (2007) and Hunt and Bullen (2007) have provided reliable information as to how prevalence rates were calculated and the data is summarised in Table 6.

Os acromiale	True prevalence	
	8.1% (22/270)	Edelson *et al.* (1993)
	5.4% (128/2367)	Sammarco (2000)
	6.2% (62/1000)	Boehm *et al.* (2005)
	6.4% (6/93)	Burbank (2007)
	Crude prevalence	
	8.3% (133/1594)	Hunt and Bullen (2007)

Table 6: True and crude prevalence rates of os acromiale reported by clinicians
Note: true prevalence derives from the number of acromia affected compared to the number of acromia available for study. Crude prevalence derives from the number of patients with the condition over the number of patients available for study.

These studies show prevalence rate ranges for os acromiale of between 1% and 15% of people, as indicated by Resnick (2002c) and Boehm *et al*. (2005). However, as the condition can be completely asymptomatic in certain patients and therefore be discovered accidentally (Gumina *et al*., 2003), it is expected that the prevalence of os acromiale in the clinical literature is actually higher than reported.

Bilateral involvement has been reported to occur in a ratio of 1:3 or less of shoulders analysed. For instance, none of the six of 93 shoulders of patients affected by the condition were bilaterally involved in a study conducted by Burbank *et al.* (2007), but Sammarco (2000) found that 32 of 96 skeletons were bilaterally affected giving an overall frequency of 33.3%. Similarly, Edelson *et al.* (1993) found the condition to be bilateral in 10 of the 22 shoulders of patients analysed, and Pagnani *et al*. (2006) found that two of their 12 patients were affected bilaterally. The dominant arm appears to be affected more often than the non dominant arm, as reported by Demetracopoulos *et al.* (2006) and Pagnani *et al.* (2006), probably as a consequence of differential stress being placed on each arm (assuming it is related to physical stress).

(ii) Os acromiale and age

With some variation, the ossification centre at the distal end of the acromion fuses around the age of 25 years according to Resnick (2002c), or between the age of 18 and 20 years according to Scheuer and Black (2004:259). For instance, Sammarco (2000) found that os acromiale was present in three of the 31 skeletons studied aged between 18 and 21 years (9.7%), giving no significant difference between the frequency in this age group and that in adult skeletons older than 21 years of age (8.0%).

Among the young, Demetracopoulos *et al.* (2006) reported os acromiale in a 16 year old athlete. Pagnani *et al.* (2006) found os acromiale in competitive athletes during late adolescence and early adulthood, with ages ranging between 18 and 25 years. Despite the relatively young age of their patients, and their affirmation that complete fusion of the apophysis may not occur until 25 years of age, they emphasised that spontaneous fusion failed to occur.

In the older age groups, Boehm *et al.* (2005) reported patients aged on average 56 years at the time the condition was found, and Gumina *et al.* (2003) describe 11 cases of os acromiale in male and female patients whose average age was 48 years (range 37-66 years) and 54 years (range 29-79 years) respectively.

(iii) Os acromiale and sex

Os acromiale affects men more frequently than women according to Sammarco (2000). In his study of 67 scapulae, the prevalence rate in men was found to be 8.5% compared to 4.9% in women. A number of clinical studies such as that of Gumina *et al.* (2003) and Pagnani *et al.* (2006) support this finding. On the other hand, Boehm *et al.* (2005) did not find differences in the prevalence of os acromiale between males and females. They believed that the reason could be due to differences in the population studied by that of Sammarco (2000); Boehm *et al.* (2005) examined a Caucasian population of 1000 patients from a small region in Germany whereas Sammarco (2000) studied a population double that size from a mixed ancestry in the USA.

(iv) Aetiology

The aetiology of os acromiale has two rival hypotheses. The most popular explanation is that the condition results from mechanical stress and trauma on the developing acromion, leading to non-fusion. The second hypothesis on the other hand, suggests that the condition has an underlying genetic predisposition.

(a) Trauma theory

Those defending the former theory (Pagnani *et al.*, 2006; Demetracopoulos *et al.,* 2006) believe that os acromiale is the result of an overuse injury. In other words, persistent motion and repetitive trauma exerted on an unstable acromion will eventually lead to a failure of the ossification centre to fuse. According to Pećina and Bojanić (1993:36-7) the risk of developing os acromiale is much higher in people engaged in physically demanding lifestyles and strenuous occupations. For instance, athletes engaged in “overhead” sports, such as volleyball, handball, tennis, badminton or swimming, where repetitive overhead arm motions are combined with abduction and external rotation of the arm, are at higher risk of developing the condition. In line with this idea, Demetracopoulos *et al.* (2006) reported os acromiale in a female fast-pitch softball pitcher who suffered pain with overhead arm movements and throwing rather than when performing normal daily activities. Pagnani *et al.* (2006) found os acromiale in 12 elite athletes engaged in overhead arm actions, and 10 of them competed in American football, with two being basketball players. Evidence of other activities and physically demanding lifestyles other than sports causing os acromiale has also been reported. Warner *et al*. (1998) describe os acromiale in the shoulder of a plumber, and Peckett *et al.* (2004) in the shoulders of 18 manual workers, although it was not specified which particular activity was involved.

A sex bias also tends to favour the trauma theory according to Case *et al.* (2006) following the assumption that a sexual division of labour and/or a sport preference exists between male and females. Similarly, a side bias would also support this theory as this would be related to handedness and the differential stress being placed on the dominant compared to the non dominant arm. In contrast, as discussed earlier in this section, the clinical literature has provided mixed results regarding sex and side bias.

In addition, a further statement that provides support for the trauma theory is the relationship between os acromiale and osteoarthritis. In section 2.2.4 of this chapter, osteoarthritis is described as occurring secondary to trauma. Pagnani *et al.* (2006) found degenerative changes at the acromio-clavicular joint in five of their clinical cases. Similar results were found by Edelson *et al.* (1993) and Sammarco (2000) who worked with skeletal remains and observed osteoarthritic changes on adjacent surfaces of the acromio-clavicular joint.

Finally, although less commonly observed, os acromiale can be found associated with a single traumatic episode as opposed to repetitive trauma. For instance, Pagnani *et al.* (2006) found that two of their twelve patients affected by the condition could recall a specific injury, whereas repeated trauma appeared to be the contributory aetiological factor in the remainder.

(b) Genetic theory

Supporters of the second theory believe that os acromiale is an inherited condition. The best evidence for a genetic aetiology for os acromiale would be studies involving twins or families. Indirect evidence supporting the heritability of the condition was presented by Angel *et al.* (1987) based on a study of skeletal remains from the cemetery of the first African Baptist Church from Philadelphia (USA). The authors suggested the possibility of a familial inheritance of the condition because they found a high frequency of os acromiale amongst individuals buried in the same family clusters. However, a thorough search of the clinical literature suggests that such studies have either not been undertaken, or supporting evidence does not exist. This incongruity is even more surprising particularly when authors such as Resnick (2002c) have described the condition under the section "congenital diseases" of his book and no evidence of this kind is provided.

According to Case *et al.* (2006), if the aetiology of os acromiale is primarily genetically induced, one expectation would be that related populations would show similar frequencies than genetically distant populations. In addition, a second expectation if the condition is chiefly genetic would be that os acromiale would not show a side bias, as this would tend to favour the mechanical aetiology and possible differential stress related to handedness. In line with these ideas, two studies, one by a clinician (Sammarco, 2000) and the other led by two anthropologists (Hunt and Bullen, 2007) support these assumptions. These authors found high true and crude frequencies of os acromiale affecting both shoulders of black men (44.7% and 11.1%), when compared to a white group (22.4% and 5.3%), respectively. Although, according to Case *et al.* (2006), these results could be indicative of the relatively recent shared genetic ancestry of African groups, it could be argued that if closely related populations exhibited similar frequencies of os acromiale then it can reasonably be suggested that their lifestyles placed similar stresses on the developing acromion.

(c) Other

A more eclectic vision is the idea proposed by Case *et al.* (2006), where os acromiale would result from a combined aetiology. In other words, the authors do not deny the genetic potential involved in the expression of the condition, although this will also depend on the threshold level of mechanical stress sustained by certain individuals during adolescence.

Other possible aetiological factors have been proposed by Gumina *et al.* (2003) where the authors attribute the presence of os acromiale to the particular position of the acromio-clavicular joint of the shoulder. They suggested that the greater the distance between this joint from the anterior edge of the acromion, the higher the chance of os acromiale. However, Boehm *et al.* (2005) could not confirm the relationship between the presence of os acromiale and the acromio-clavicular joint position because two-thirds of the meso-acromiale could not be classified into one of the groups reported by Gumina *et al.* (2003).

2.4.5 Symptoms

The commonest symptom of os acromiale reported in the clinical literature is shoulder pain. According to Pećina and Bojanić (1993:36) excessive repeated strain placed on the upper extremity of the acromion can lead to os acromiale and impingement syndrome of the shoulder joint. There are two possible explanations for how the acromial fragment produces pain in the shoulder. Sammarco (2000) and Demetracopoulos *et al.* (2006) suggest that this can result from significant motion at the acromion-clavicular joint, or as consequence of the downward force generated by the *M. deltoideus* that inserts into an unstable acromion and impinges on the rotator cuff tendons during contraction. On the other hand, Sammarco (2000) did not disregard the possibility of degenerative changes and osteophytic spurring at the acromio-clavicular joint as contributory sources of shoulder pain and impingement syndrome.

Besides suffering from impingement-like pain, other symptoms have been reported. For instance, patients seen by Pagnani *et al.* (2006) experienced shoulder pain with overhead movements associated with weightlifting. Night pain, as well as the inability to sleep on the affected side, were also common symptoms. On the contrary, os acromiale may be completely asymptomatic and the condition may be discovered accidentally when radiographs of injured patients are obtained, as reported by Edelson *et al.* (1993). Mixed results are also possible. For instance, Gumina *et al.* (2003) found that in their sample of 33 patients with os acromiale, 11 (nine males and two females) were asymptomatic and 22 (16 males and six females) were symptomatic.

2.4.6 Os acromiale and bioarchaeology

For a number of years and well into the late 1960s and 1970s os acromiale was regarded by anthropologists and bioarchaeologists as one type of phenotypic variation, in other words, a non-metric or epigenetic trait (Tyrrell, 2000). For this reason it has often been employed along with other traits to provide insight into levels of interbreeding, gene flow and population distances (Tyrrell, 2000). An example of this approach is the study by Angel *et al.* (1987) where os acromiale was used along with other traits to denote genetic distances and “family groups” within a cemetery. However, in recent studies os acromiale has been suggested as a culturally induced trauma, as a consequence of a functionally related injury due to repetitive movements placed on the acromio-clavicular joint rather than a genetically induced trait.

Os acromiale is in general terms a condition rarely seen or not often reported in the bioarchaeological literature. For this reason, little is known about the global variation of this condition as most information comes from Europe and North America.

A review of studies with available data on prevalence rates for European skeletal samples is summarised in Table 7. The majority of information comes from the analysis of British skeletons covering a long diachronic period. For instance, Roberts and Cox (2003) provided a summary of cases of os acromiale reported in published and unpublished skeletal reports. Some information regarding this condition during the late-medieval period was also provided by Knüsel (2007) when analysing the skeletal remains of the soldiers that fought in the battle at Towton in AD 1461 in North Yorkshire. Stirland (2000) analysed skeletons dating to AD 1545, belonging to the crew of the sunken ship called the Mary Rose. In a different paper, Stirland (1996) analysed a medieval skeletal population buried at St. Margaret Fyebridgegate in Norwich, Norfolk. Post-medieval data for os acromiale are known from Miles (1994) who analysed a series of skeletons excavated from a small island in the western Isles of Scotland. In Victorian England, Arabaolaza *et al.* (2007) found examples of os acromiale among those buried in the cemetery associated with St. Peter’s Collegiate Church in Wolverhampton (West Midlands). In continental Europe, Case *et al.* (2006) studied the prevalence of os acromiale in a medieval skeletal Danish population.

	Prevalence	Period	Reference
Os acromiale	True 10.0% (11/110)	Post-medieval	Miles (1994)
	Crude 3.3% (10/308)	Roman	Roberts and Cox (2003)
	Crude 2.6% (27/1057)	Early Medieval	Roberts and Cox (2003)
	Crude 5.1% (19/368)	Medieval	Stirland (1996)
	Crude 13.6% (15/110)	Medieval	Stirland (2000)
	Crude 7.7% (41/532)	Medieval	Case *et al.* (2006)
	Crude 10.3% (3/29)	Late-medieval	Knüsel (2007)
	Crude 4.3% (4/92)	Victorian	Arabaolaza *et al.* (2007)

Table 7: True and crude prevalence rates of os acromiale reported by bioarchaeologists
Note: true prevalence derives from the number of acromia affected over the number of acromia available for study. Crude prevalence derives from the number of skeletons with the condition over number of skeletons available for study.

In the Americas, information on os acromiale is very scarce. A search on the five year index (2003-2007) of the programme of the Paleopathology Association meetings and the seven year index (2001-2008) of the programme of the American Association of Physical Anthropology meetings did not bring up any examples of studies reporting information on this topic in Native American populations. With the exception of Angel *et al.* (1987) who found the highest frequency reported (30%) for os acromiale among historical individuals buried in the cemetery of the first African Baptist church in Philadelphia (USA), all available information on os acromiale among Amerindian groups comes from an old paper written by Vallois (1925). The author analysed the presence of os acromiale globally and found a crude prevalence rate of 33.3% (1/3) among Eskimos but did not find examples present among 14 skeletons belonging to

North American Amerindians from California, Canada and Mexico. The condition was also absent in individuals from Venezuela, Brazil, Bolivia and Paraguay and from skeletons of Araucanos and Fuegians from Argentina. However, the condition was present in Amerindians from Ancón, Peru at a frequency rate of 3.5% (1/28) and Patagonians from Argentina (22.2% or 2/9). The information pulled from all Native Americans revealed a crude prevalence rate of 4.9% (4/81) and a true prevalence rate of 3.9% (7/176). According to Vallois (1925), os acromiale was an uncommon condition among Native American Indians compared with other populations.
In summary, the reported true and crude prevalence rates of os acromiale in bioarchaeology range between 1% and 15% as observed clinically (Resnick, 2002c; Boehm *et al*., 2005). However, the prevalence of os acromiale varies widely depending on the recording method used.

(i) Os acromiale and activity

Studies of the aetiology of os acromiale in skeletal remains are rare. However, a few examples are worthy of mention. For instance, Stirland (2000) presented evidence for an association between os acromiale and archery. She analysed the skeletons belonging to the crew of the Mary Rose, a 16th century British warship. According to the written records, associated with the Mary Rose, the men on board were mariners (200), soldiers (185) and gunners (30) as well as officers and commanders. Stirland (2000) suggested the highest frequency of the condition among the skeletons recovered (26 of 207 scapulae, 12.5%) was found within two specific sections of the ship where archery equipment such as longbows and arrows were stored. Unlike modern bows whose weight ranges around 20kg, medieval bows were nearly four times heavier than their predecessors, with an estimated weight of 75kg. It is therefore assumed that the action of drawing the bow and firing arrows on a regular basis from a young age may have prevented the acromial epiphysis from uniting. As Stirland (2000) found a slightly increased frequency of os acromiale on left scapulae (15 compared to 11 of 26 scapulae analysed) the author suggested that the explanation for this would be in the technique employed by the archers. Assuming that the archer was right handed, the left arm holds the bow (the one that most modern archers use). The elbow of the drawing arm is fully

flexed, with the fingers pulling the string. The technique required to draw the bow involves laying the body into the bow using the strength and weight of the body. Not surprisingly, in modern archery the non-drawing shoulder (usually the left) appears to be the major area of discomfort (Mann and Littke, 1989). As this would have put a greater stress on the muscles of the left shoulder than those of the right, the author concluded that the technique employed by the archers could account for the dominance of os acromiale in left acromia.
In line with this study, Stirland (1993) conducted a study to compare bilateral asymmetry between humeri of the Mary Rose skeletons in order to observe if the asymmetrical pattern in os acromiale was also expressed in humeral dimensions. The study revealed that the measurements taken of the diameter of the head of humeri, as well as at the greater tubercle, exhibited larger dimensions on the left shoulder in comparison to the right, suggesting that the forces exerted in drawing the longbow would have also been transmitted to the arm.

Stirland’s (2000) original idea was supported by a study conducted by Knüsel (2007) of skeletons of soldiers who fought in the battle at Towton in AD 1461 in North Yorkshire (UK). He found os acromiale in three of the 29 soldiers (two bilaterally affected and one affected on the left acromion). The author suggested that the condition may have been related to archery as well as to overhead rotational movements associated with the use of projectiles in general. He also suggested that early participation in such activities prior to complete ossification of the acromion process could have accounted for the apparent high frequency of os acromiale among these medieval groups.

In summary, if the possible connection between os acromiale and archery as suggested by Stirland (2000) is true, modern archers should also present the condition. However, there is no such information published to date. This is probably to do with the fact that as highlighted above, medieval bows weighed nearly four times more (75kg) than modern ones (20kg), thus not inflicting significant stress on the acromio-clavicular joint to produce the condition. At the present time, it seems there is insufficient evidence to support or reject this idea and this could be extended to the genetic-hereditary explanation.

Outside of this line of thinking, Wienker and Wood (1988) proposed a different occupational interpretation to the presence of os acromiale. They reported a forensic case of a mature adult male who was found in a ditch near Dade city, Florida (USA). The person was believed to have been a migrant engaged in citrus harvesting. As well as os acromiale on the left shoulder the individual exhibited a number of other skeletal features such as enthesopathies and osteoarthritis at various sites and joints, squatting facets on both tibiae and well-healed fractures of several ribs. The presence of these conditions allowed the authors to suggest that this individual endured a lifestyle of prolonged occupational stress compatible with citrus harvesting, the primary economic activity of the Dady city area industry. The ethnographic evidence provided substantial confirmatory evidence as, according to the accounts, migrant citrus workers used to routinely carry long and heavy ladders, as well as their bags of fruits, weighing up to 40kg over the left shoulder. This in turn could have contributed to extra stress placed upon the acromial area, according to the authors. Although a few months later a missing person fitting this biological profile was reported, the medical records related to him could not be located making it difficult to confirm that the remains described were those of the missing individual.

2.4.7 Limitations and future research

Some of the limitations encountered in the analysis of os acromiale are related to the discrepancy encountered between the clinical and the bioarchaeological diagnosis of the condition. This is important because misdiagnosis can certainly lead to marked prevalence differences between both disciplines and the impossibility of performing future comparative studies. For instance, as discussed in section 2.4.3, os acromiale can be under-diagnosed if only symptomatic shoulders are radiographed or if the detection method used is sensitive or not. On the other hand, diagnosis in bioarchaeology has the advantage of direct visualisation of the condition, although the degree of preservation as well as the availability of complete scapulae for study can also lead to prevalence bias.

In addition to this, the limited knowledge that bioarchaeologists have of os acromiale is probably due to the scarcity of published studies. Although a vast body of information exists in the form of reports and monographs, they are not always easy to access, particularly if they remain unpublished. Access and availability to such information can even be more challenging if the search expands outside Europe.

Due to clinicians and bioarchaeologists tending to focus on different issues regarding os acromiale, especially with respect to determining aetiology, future research needs to involve participation in collaborative studies where the expertise of both professionals is combined.

2.5 Osteochondritis dissecans

In this section clinical and bioarchaeological aspects of osteochondritis dissecans are reviewed. A number of aspects including the epidemiology of the condition as well as its aetiology and possible connection with physical activity are presented in light of the clinical information. Similar aspects are also covered from a bioarchaeological perspective.

2.5.1 Definition

Osteochondritis dissecans (OD) belongs to a group of disorders, the so-called osteochondroses, or a heterogeneous group of conditions that affect the joints of the immature skeleton. They are characterised by fragmentation, collapse, and sclerosis as well as reossification and reconstitution of the articular surface (Resnick, 2002b). It is a condition in which a small fragment of articular cartilage, or both cartilage and subchondral bone, detaches gradually from its normal position at the joint (Dandy and Edwards, 1998:325; Ortner, 2003:351-2) (Fig 10).

Figure 10: Developing stages of osteochondritis dissecans (Bradley and Dandy, 1989: 519)

The osteo-cartilaginous fragment or fragments may remain *in situ*, be displaced or become a loose body within the joint cavity, or at other times it can be resorbed or undergo revascularisation and new bone formation if it maintains attached to its original location site (Resnick, 2002b). Cartilaginous fragments can continue growing and calcify but bone fragments necrose and remain unaltered in size and shape. The subchondral bony defect from which the sequestrum detaches can heal over time although there will always be a depression on the bony articular surface (Ortner, 2003:351-2), often known as the “crater” (Apley and Solomon, 1993:105). This lesion as well as the loose body trapped inside the subchondral crater varies in depth, size and shape (Rogers and Waldron, 1995:28).

2.5.2 Terminology and classification

The term osteochondritis dissecans was first coined by König in 1887 and is, for this reason, commonly described in the clinical literature as König's disease. However, the term has received criticism from several scholars (Barrie, 1987; Bradley and Dandy, 1989) for being inaccurate, loose and leading to the description of any condition representing a separation of cartilage and/or bone as OD. For instance, the term "post-traumatic subarticular necrosis" has been used as synonym for osteochondritis dissecans (Aufderheide and Rodríguez-Martín, 1998:81) although, according to Barrie (1987), this represents a different entity. Other terms such as "intra-articular fracture", "flake fracture", "osteochondral fracture" (Ming *et al.*, 2004) and "transchondral fracture" (Aufderheide and Rodríguez-Martín, 1998:81) have also been used as synonyms for OD although, in Resnick's opinion (2002b), the last term represents a different condition.

With regard to its classification, despite there being no standardised system for the morphological changes occurring in OD (Resnick and Goergen, 2002), in general terms, two main features tend to be consistently described. Firstly, the location of the lesions of OD within the joints uses a classification that is more commonly associated with the knee joint because this location alone accounts for more than 70% of osteochondritic cases. Despite there being no unified criteria as to the chosen classification system from author to author, Aichroth (1971) provided a graphical method of recording the location of the lesions in the femoral condyles that is still used today (Uematsu *et al.*, 2005) (Fig 11).

Classification of OD locations outside of the knee joint is very rare. This is perhaps because the majority of studies of OD of other joints are reports of individual cases that do not follow any specific classification system. Instead they provide a description of the OD lesion found and its particular location. Examples of this kind are exemplified by Wuelker and Peters' (1996) study of OD on the head of the first metatarsal, Bui-

Mansfield *et al*. (2000) on the tibial plateau, Bauer *et al.* (1987) at the ankle joint and Desai *et al*. (1987) on the patella.

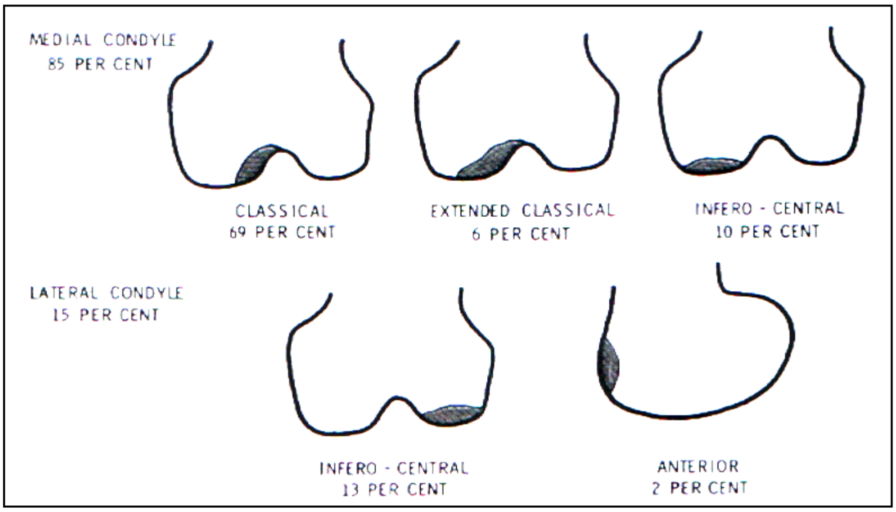


Figure 11: Site of locations of OD of the knee according to Aichroth (1971: 440)

The second main feature of OD classification systems is the degree of radiographic development of the abnormality. With some variants, they range from intact cartilage to detection of cartilage disruption, finishing with a detached osteochondral fragment as a result of the tissue's inability to recover and repair. There is no consensus either for this feature. However, within the ankle joint, a few authors such as Smith and Chang (1998) and Ming *et al*. (2004) have found the staging classification system proposed by Berndt and Hardy (1959) for the talar dome to be useful.

2.5.3 Location

As suggested above, one of the two most important features regarding osteochondritis dissecans is the location of the lesion. Although it can develop anywhere in the skeleton, certain joints are more prone than others to suffer from the condition. For instance, Camasta *et al*. (1994) suggested that OD has a predilection for convex joint surfaces because of a convergence of impaction forces occurring in this type of joint. Although convex articular surfaces are more likely to sustain trauma-related damage, there are numerous clinical examples reporting the involvement of typically concave articular surfaces. Examples of this kind are the tibial plateau (Towbin *et al*., 1982), the glenoid fossa of the scapula (Shanley and Mulligan, 1990) or the acetabulum of the os coxa (Berthelot *et al.*, 2000).

The most commonly affected joints are the knee, ankle, and elbow (Bullough, 2004a). The knee is the most affected of the three joints, particularly at the medial condyle, and osteoarthritic changes are present here in 80% to 90% of cases (Aichroth, 1971). Following the knee, the ankle is the second joint most severely affected by OD, with the talus being usually involved on the lateral and medial borders of its dome (Resnick and Goergen, 2002; Woods and Harris, 1995; Smith and Chang, 1998) as well as on the proximal surface (Schneider *et al.*, 1974). The third commonest site to find OD is the elbow with the capitulum of the humerus particularly affected (Brownlow *et al.*, 2006; Bojanić *et al.*, 2006) (Fig 12).

Figure 12: HB 40 showing OD on the capitulum of a left humerus. St. Peter's Collegiate Church, Victorian Wolverhampton, England

It has been said that OD is rare in joints other than those described above (Dandy and Edwards, 1998:325) but in reality OD is described in the clinical literature in nearly every single joint, for example on the humeral head (Debeer and Brys, 2005), on the femoral head (Wood *et al.*, 1995) and on the tibial plateau (Bauer *et al.*, 1987; Bui-Mansfield *et al.*, 2000). Ishibe *et al.* (1989) also reported a unique case of OD of the distal radio-ulnar joint. Other sites such as the first metatarso-phalangeal joint (Camasta *et al.*, 1994; Wuelker and Peters, 1996) and the temporo-mandibular joint (Campos *et al.*, 2005) are also represented. The patella can also be involved and in the majority of the cases the lesion occurs on its medial facet (Resnick and Goergen, 2002) and on the medial ridge, according to 13 cases reported by Desai *et al.* (1987).

Osteochondritis dissecans can also occur on one or multiple joints in an individual (Resnick and Goergen, 2002). For example, Aichroth (1971) reported multiple involvement examples in seven patients, affecting at least two of the knee, elbow and ankle joints.

2.5.4 Diagnostic criteria

There are a number of diagnostic tests for living people aimed at identifying osteochondritic lesions of the joints. The choice of the appropriate method to diagnose the condition will ultimately depend on the specific joint involved (Resnick and Goergen, 2002). One of the standard methods often used by clinicians is radiography. In radiographs, the type of projection taken will depend on the joint affected. However, in general terms osteochondritic lesions tend to be defined by a radiolucent line of demarcation and the presence of a "crater" when the fragment separates from its base (Apley and Solomon, 1993:104-5). As the early stages of the condition, before the fragment detaches, are not always easy to observe with radiographs, magnetic resonance imaging (MRI) or computed tomography (CT) scans are useful methods to confirm the diagnosis and to outline the extent of the lesion (Graham and Fairclough, 1998). The examples provided by Bui-Mansfield *et al.* (2000) and Debeer and Brys (2005) support the use of MRI and CT as the authors found that OD was difficult to detect on routine radiographs of the ankle joint and the humeral head. Another diagnostic method used is arthroscopy. This is usually employed as a means of verification of radiographic findings (Resnick and Goergen, 2002). For instance, Woods and Harris (1995) confirmed OD with arthroscopy where conventional radiographs showed osteochondritic lesions of the medial talar dome. On the other hand, Jaberi (2002) and Widuchowski *et al.* (2007) only used arthroscopy to establish a definite diagnosis of OD of the knee.

2.5.5 Epidemiology

(i) Prevalence

Population studies of osteochondritis dissecans are scarce. This is perhaps the consequence of it being a rare condition about which all that is known comes from individual case reports. However, a recent study has brought to light important information regarding the incidence of this condition through a large-scale study conducted by Widuchowski *et al.* (2007). They analysed the knees of 25,124 patients with the purpose of providing epidemiological information on the prevalence of various cartilaginous lesions. Osteochondritis dissecans of the knee was found in 332 patients (1.3% or 13 cases per 1,000 patients). Osteochondritis dissecans of the knee in general accounts for 85-90% of the cases reported clinically (Aufderheide and Rodríguez-Martín, 1998:82) and hence the frequency in other joints is comparatively lower. For instance, according to Bauer *et al.* (1987), the prevalence of OD of the ankle was calculated from one city hospital serving a stable population as 0.002 per 1,000, regardless of sex and age. A similar attempt to estimate the prevalence of OD in the ankle was presented by O'Farrell and Costello (1982). These authors identified 35 patients with OD of the talus in a 28-year period in three different hospitals, which represented an approximate frequency of one case in every 2.4 years, but no further analysis was given.

Population studies of other joints affected by OD, apart from those already mentioned, are unavailable and therefore prevalence information remains unknown. Furthermore, the fact that the condition can be completely asymptomatic (Resnick and Goergen, 2002) could also lead to an underestimate of true frequencies. Bauer *et al*. (1987) believe that the frequency rate of OD of the ankle is under represented owing to difficulties in visualising the defect radiologically, and the fact that several cases may heal spontaneously.

(ii) Osteochondritis dissecans and age

In general terms, it can be said that OD is a condition of the immature skeleton. The onset age ranges from childhood to adolescence according to Apley and Solomon (1993:103), childhood to middle age (Resnick and Goergen, 2002) and adolescence to young adulthood (Ortner, 2003:351). The highest frequency falls between 10 and 25 years (Rogers and Waldron, 1995:28; Aufderheide and Rodríguez-Martín, 1998:82). Several clinical studies such as that of Jaberi (2002) on OD of the knee, Brownlow *et al*. (2006) on OD of the elbow, Ming *et al.* (2004) on OD of the talus, demonstrate that, independent of the joint affected, the age of occurrence of OD falls in the middle adult age category.

(iii) Osteochondritis dissecans and sex

Osteochondritis dissecans affects males more than females (Apley and Solomon, 1993:104; Rogers and Waldron, 1995:28; Ortner, 2003:351) and is twice as common in the former group than in the latter. This seems to be the norm observed for all joints as seen in clinical studies of the knee (Jaberi, 2002; Uematsu *et al*., 2005), elbow (Brownlow *et al*., 2006), ankle (Ming *et al*., 2004), patella (Desai *et al*., 1987) and shoulder (Shanley and Mulligan, 1990; Debeer and Brys, 2005). However, according to Aufderheide and Rodríguez-Martín (1998:82), the number of women affected by OD rises after the menopause. The reason why males are probably more affected than females may be because they are more actively involved in sport which, in turn, would imply a traumatic cause (Ming *et al*., 2004).

(iv) Aetiology

The cause of OD is uncertain and sometimes assumed to be multifactorial. The most popular theories will be now explained in further detail.

(a) Ischaemia theory

Although modern clinical studies do not deny the possible connection that OD might have with circulatory disturbances, the popularity of this theory as a causative explanation of OD has waned over the years. This is perhaps because other theories are stronger and supported with more empirical evidence. It is however worthy of mention because of its historical interest. Supporters of the ischaemic theory believed that interruption to the normal blood supply led to cartilage and bone death, followed by their consequent separation from the joint (Campbell and Ranawat, 1966; Enneking, 1977:147). The latter attributed the onset of OD of the knee to an insufficient blood supply to the subchondral bone. This in turn resulted in necrosis of the bone located immediately beneath the articular cartilage. Any additional trauma would have fractured the overlying articular cartilage, giving rise to a loose osteochondral fragment. However, an earlier paper (Rogers and Gladstone, 1950) on the vascularity of the distal end of the femur contradicted Enneking's work; they found that the condylar area of the femur has a rich blood supply with abundant intramedullary anastomoses. Therefore, they suggested that ischaemia was an unlikely etiological factor for OD of the knee. Similarly, in the ankle, Bauer *et al.* (1987) pointed out that a poor blood circulation was perhaps a responsible factor for OD of the ankle but contrary to this idea, Bui-Mansfield *et al.* (2000) suggested that OD at this site was unlikely to result from vascular problems as the ankle has a rich arterial supply.

(b) Accessory centres of ossification theory

As with the ischaemia theory, the accessory centres of ossification theory has few supporters in the clinical literature. Some authors have proposed that OD in young patients results from pre-existing anomalous centres of ossification that predispose the joints to this condition. Traumatic events to the affected osteochondral segment results in partial or complete separation. For instance, Ribbing (1955) compared the radiographs of children with OD of the knee with those who had evidence of detached bony islands within the articular cartilage and found the location to be similar. He then proposed that the aetiological mechanism that triggers OD was an accessory bone ossification centre detached during childhood, with a possible subsequent partial reattachment. Subsequent episodes of trauma led to complete separation of the chondral surface and the typical osteochondritic lesion. Caffey *et al.* (1958) also analysed the radiographs of children who had irregularities in the outline of the distal femoral condyles and found that certain patients presented lesions that resembled those with OD. They hence suggested that these abnormalities could be somehow linked with the development of OD in children. Sontag and Pyle (1941), who in previous years also noted the presence of roughening and irregularities of the epiphyseal femoral outline, concluded that these were normal variants associated with acceleration in skeletal growth. Their case therefore constitutes an argument against the abnormal ossification centres theory being associated with OD, as these defects can actually be the result of normal development. However, Cetik *et al*. (2005) believed that the development of bilateral OD of the knee in a 20-year-old patient supports the fact that a defect in the ossification centres may be the aetiology of the case reported.

(c) Genetic theory

Osteochondritis dissecans has also been linked to underlying genetic factors, probably transmitted as an autosomal dominant trait (Bullough, 2004a). Several studies have documented families with a predisposition for OD in various joints. For instance, Woods and Harris (1995) suggested that the presence of OD of the talus in identical twins indicated an underlying predisposition to the condition, probably of an inherited nature. Phillips and Grubb (1985) analysed three cases of OD affecting multiple joints in a family of four generations and found that the pattern occurred in an autosomal dominant fashion with a predisposition towards individuals of short stature. Dwarfism has also been reported to be associated with OD (Andrew *et al*., 1981) although this would support the genetic theory only in isolated cases. On the other hand, Petrie (1977) failed to establish any hereditary connection for the condition in first degree relatives of 34 patients with OD of the knee, ankle and elbow. In line with these results, O'Farrell and Costello (1982) also failed to find any kind of family history in their study of 24 patients with OD of the talus.

Although modern clinical studies do not deny the possible connection between OD and genetic factors, the condition is more likely to result from trauma.

(d) Trauma theory

The popular consensus is that trauma is the major aetiological factor of OD (Resnick and Goergen, 2002). In line with this idea, Pećina and Bojanić (1993:3-4) also emphasise that OD results from repetitive stress and microtrauma and therefore they include the condition under the group of musculoskeletal overuse injuries. Osteochondritis dissecans can also result from a stress fracture of an unfused epiphysis (Apley and Solomon, 1993:103) which, according to Pećina and Bojanić (1993:327), represents a variant of overuse injuries.

A number of clinical studies support the idea that trauma or microtrauma may play an important role in the aetiology of OD, particularly among sports people. Although the condition is particularly high among young people who engage in sports and therefore are exposed to repetitive trauma or microtrauma (Aufderheide and Rodríguez-Martín, 1998:81), overuse injuries can also develop in non-athletes as a result of normal human activity including work (Pećina and Bojanić (1993:4). In the knee, for instance, Widuchowski *et al.* (2007) and Jaberi (2002) observed, respectively, that 45% and 55% of their patients with OD recalled a previous traumatic event as a consequence of a sports injury or vehicular accident. According to an analysis performed by Desai *et al.* (1987) of patients with OD of the patella, the authors also determined that lesions resulted from repeated minor trauma, as all but one of their patients had injured their patellae in sport or at work. Similarly, Ming *et al*. (2004) and O'Farrell and Costello (1982) found that in the talus, 77% and 91%, respectively, of their patients had a history of trauma present at the time of first consultation. Furthermore, Shanley and Mulligan (1990) analysed two individuals with OD of the glenoid cavity of the scapula whose clinical histories also indicated a traumatic aetiology.

Experimental studies performed on animals (Tomatsu *et al*., 1992) as well as biomechanical analysis of human cadaveric material (Athanasiou *et al.*, 1995) also reinforce the acquired-traumatic aetiology of OD. On the other hand, the strongest argument against the traumatic-acquired theory in the aetiology of OD is the lack of any traumatic event associated with its presence. A number of clinical studies (Wuelker and Peters, 1996; Jaberi, 2002; Debeer and Brys, 2005) have reported that few or sometimes none of their patients could recall any obvious traumatic event related to the lesion. This could therefore suggest that trauma does not necessarily totally explain the aetiology of OD and therefore a multifactorial aetiology could not be ruled out.

The joint affected by OD will ultimately depend on the physical activities, sports and occupations involved. In this respect, there is an extensive bibliography regarding the association of OD of the elbow and sporting activities. For instance, Brownlow *et al*. (2006) found that their patients with OD of the humeral capitulum practised a range of sports such as rugby, gymnastics, tennis, baseball, javelin, netball squash and waterpolo. The condition affected the dominant arm in 55% of cases of these Olympic professionals and recreational sports patients. In a similar study, Bojanić *et al.,* (2006) also found OD of the humeral capitulum in three high level gymnasts. According to Pećina and Bojanić (1993:328) and Klingele and Kocher (2002) the “little league elbow” is the term applied to the overuse injury sustained by children and adolescent throwers, as a consequence of the repetitive trauma of throwing a ball, for example those who are baseball pitchers. Overuse injuries of this kind take place more frequently in the growing articular cartilage of young athletes as this is less resistant to repetitive microtrauma than adult cartilage. The mechanism involved in the injury is displacement strain applied to the distal end of the elbow, with compression and traction forces exerted medially and laterally (Pećina and Bojanić, 1993:328). These movements tend to be more apparent during the late cocking and early acceleration phases of throwing according to Klingele and Kocher (2002).

Within the ankle joint, Schneider *et al.* (1974) reported OD in one female ballet dancer involving the superior articular surface of the talar dome. A similar case was found by Smith and Chang (1998) located on the lateral aspect of the left talar dome of a swimmer who sprained his ankle as a consequence of dry-land training while running and walking. The lesion was related to an inversion injury and became particularly painful with plantar flexion. According to Resnick and Goergen (2002), the combination of plantar flexion with inversion forces, followed by rotation of the tibia on the talus, produces compression of the talus, which eventually leads to a loose fragment formation. This was the case in patients seen by Smith and Chang (1998) and O’Farrell and Costello (1982). Activity-related lesions associated with OD of the femoral condyles in the knee are less reported. The mechanism of the traumatic event is not clear but, according to Resnick and Goergen (2002), it might be related to rotational forces taking place on the fixed weight-bearing knee.

Additional information on some of the physical activities linked to OD of other joints outside the three popular locations, are provided for the 2nd or 3rd metatarsal (Apley and Solomon, 1993:720) and the patella (Desai *et al*., 1987). In the former, OD can result from running or after unaccustomed activity according to Apley and Solomon (1993:720). In the patella Desai *et al.* (1987) found that their patients with OD were engaged in activities such as school sports and athletics, wrestling, gymnastics, ballet and military service. As most of the lesions were located on the medial facet of the patella, the authors suggested that only in extreme knee flexion would the patello-femoral contact have transmitted forces that led to OD. These findings are coincidental with the concept that, historically, the cause of pain in OD of the patella starts when the knee is flexed under load, according to Resnick and Goergen (2002).

A final statement should be made regarding the link between OD and osteoarthritis. It has been discussed in section 2.2.4 of this chapter that OA can occur secondarily to trauma. Long term follow up studies have shown that OD can lead to OA later in life (O'Farrell and Costello, 1982; Bauer *et al.*, 1987; Twyman *et al.*, 1991; Uematsu *et al.*, 2005), especially if the condition was diagnosed after the closure of the growth plate. This is because OD in children has a good prognosis because the condition has a high chance of healing and disappearing leaving little evidence of its presence, as observed in the study of Debeer and Brys (2005).

(e) Ethnic origin

A search of "Medline" did not reveal any comparative analyses of OD frequency in populations of different ethnic origin. However, this subject is discussed in section 2.5.7 in relation to prehistoric populations from different genetic backgrounds, countries and continents.

2.5.6 Symptoms

The signs and symptoms of OD vary depending on the site involved. It can produce chronic pain, swelling and "locking" of the joint if the necrotic fragment becomes loose, as well as recurrent episodes of "giving way" or even effusion in the joint (Bullough, 2004a). These can be aggravated by movement, producing limitation of motion and "clicking". However, in some cases the lesion can be completely asymptomatic (Resnick and Goergen, 2002) being only discovered accidentally.

2.5.7 Osteochondritis dissecans and bioarchaeology

Osteochondritis dissecans has received little attention in bioarchaeological studies. It has remained largely neglected because the condition is not commonly seen in skeletal samples (Stirland, 1991:43) and also because there are a number of other conditions observed in skeletal remains that can be confused with it. Among these,
OA, as well as taphonomic abnormalities (Loveland *et al*., 1984), normal concavities and pitting (Rogers and Waldron, 1995:29) and developmental defects (Roberts and Cox, 2003:400) have been mentioned. However, the analysis of OD in human skeletal remains allows observers to see all developmental stages of the condition, including lesions in the process of healing; this is something not always possible for clinicians as they rely almost entirely on observing radiographs to diagnose the condition. However, as discussed in section 2.5.4 of this chapter, this is not always a reliable method.

(i) Osteochondritis dissecans and location

Two of the most systematic works undertaken in this field that provided valuable contributions to the study of OD, is that of Wells (1974) of Romano-British and Anglo-Saxon skeletons, and the diachronic analysis performed by Roberts and Cox (2003:71, 80, 151-2, 209) in British archaeological samples. Wells (1974) found that the commonest locations, in at least 95% of the cases, were in the medial femoral condyle and the talus. In the former, the occurrence was not as predominant as seen in clinical cases, and in the latter the lesion tended to occur on the inferior surface of the bone, contradicting clinical data (superior surface).
According to Wells (1974) OD of the elbow is rarely found in skeletal material but, when it occurs, it is usually located in the capitulum of the humerus (Fig 12). In contrast, the wrist joint, particularly the distal end of the radius where it articulates with

the scaphoid, is a relatively common site for the lesion. The intervertebral articular facets (usually of the cervical vertebrae), the head of the humerus and the tibia (lateral and medial condyles) are also sometimes affected. A rare location is the glenoid cavity of the scapula. According to Wells (1974) this is because the shoulder is a joint not subject to the same compression forces as the knee or the spine. The acetabulum of the innominate is, in contrast to clinical studies, a more frequently affected location in skeletal samples than the head of the femur. It is not known if this phenomenon results from poor radiographic observation or the fact that the condition is over diagnosed by bioarchaeologists who confuse osteochondritis dissecans with other conditions or anomalies of the cortical bone.

In the feet, OD of the navicular, 1st metatarsal (head and articulation with the 1st cuneiform) and the 1st hallucial phalanx (Fig 13) are also common sites for OD. The ankle (distal joint surface of the tibia) (Fig 14) is also a very common location for osteochondritic lesions among Romano-British and Anglo-Saxon samples, although it occurred less often in the Bronze Age populations (Wells, 1974).

Figure 14: F1065 showing bilateral OD of the 1st hallucial phalanges. AD 10th-16th centuries, Fishergate House, York, England

Figure 13: F1087 showing OD of the distal end of the left tibia. AD 10th-16th centuries, Fishergate House, York, England

The diachronic study of Roberts and Cox (2003:71, 80, 151-2, 209) on OD in British archaeological samples was based on published and unpublished skeletal reports. They summarised the presence and location of the condition over time by reporting crude prevalence rates for the condition. For instance, during the Neolithic period, OD was more commonly seen located in the knee joint but in the Bronze and Iron Ages OD was very rare. The Roman period witnessed an increase in the number of cases of OD of the knee. This trend was also observed by Wells (1974), who reported that OD was much more common among Romano-British and the Anglo-Saxon populations than among earlier Bronze Age peoples. Finally, in the early medieval period the number of osteochondritic cases of the knee increased further relative to the Roman period. According to this study, there is no evidence of OD for the late and post-medieval periods (Roberts and Cox, 2003:359) although is possible that the condition existed (Roberts, pers. comm. 2007). Wells (1974) also arrived at a similar conclusion as he noticed that OD was rare in British skeletal material during the 16^{th} to 19^{th} centuries AD. However, there are a number of later studies such as that of Coughlan and Holst (2007:61), and also by Stirland (1991, 1996) and During *et al.* (1994) providing examples of osteochondritic lesions during these periods. The former authors for instance, reported one individual with bilateral OD affecting the tibial condyles from the battle of Towton (AD 1461), North Yorkshire, England. Stirland (1991:43-4) found 23 joints affected by OD among the skeletons of sailors recovered from the Mary Rose, an English warship that sank in AD 1545. In 16 cases, the lesions were located on the humeral condyles, seven on the femoral condyles and seven on the femoral heads. An individual with OD of the distal humerus was also described by During *et al.* (1994) in a skeleton of a young sailor recovered from the sunken Swedish warship Vasa in AD 1628. Finally, Stirland (1996) found eight individuals buried in a late medieval parish cemetery dated from AD 1245 to AD 1468 from Norwich, England with OD in the femoral heads and condyles, humeral condyles and the talar dome.

In Victorian England, there is evidence of OD affecting the distal humerus of three individuals and an unusual example of an individual affected in both condyles of the right femora; these were all individuals buried at St. Peter's Collegiate Church, Wolverhampton (Arabaolaza *et al*., 2007). From the same period, Brickley, (2006:130) found 10 cases of OD in skeletons recovered from a post-medieval churchyard in Birmingham; they were mostly located on the humerus, femur, tibia, scapula and 1^{st} metatarsal.

Evidence of OD from other European skeletal samples has also been reported; Anderson (2000, 2001) describes OD in the cuboid of a medieval Italian child and the medial cuneiform of a juvenile skeleton from a Franciscan Friary cemetery in Italy dating from the 13th to 16th century AD. Bourbou (2003) reported two cases of OD in Byzantine Greece, one located in the glenoid cavity of the scapula and one in the lateral condyle of the right tibia. Janssen and Maat (1999) reported one case of OD on the right femoral condyle among the canons buried at the Saint Servaas Basilica at Maastricht, the Netherlands, AD 1070-1521, and Schultz (1981) found 15 cases of OD in skeletal material from a settlement in Southern Germany dated to 500-725 AD. The lesions were located on the temporo-mandibular joint, the superior articular process of C3, the glenoid cavity of the scapula, the trochlea of the humerus, the acetabulum of the innominate, the femoral head, the tibial condyle, the talus, the navicular, and the 1st phalanx of the big toe.

In the New World, there are few examples of OD. This could either be because the condition is rare and therefore did not affect Amerindian populations as much as in the Old World, or because it has gone unrecognised by bioarchaeologists unless the data lies in unpublished laboratory reports. There are, however, two reports of OD in the femoral condyles, one among the Crow Creek skeletons (Loveland *et al*., 1984), a proto-Arikara mass grave dated from AD 1350, and the other in the knees of three American Indian skeletal samples (Rogers, 1997). A third recently published example of OD of the knee found in a 4,000 year old Chilean mummy represents the first case reported for the southern hemisphere and perhaps the oldest case known of this kind in the continent (Kothari *et al*., 2009).

To summarise, bioarchaeological studies have also shown that, in line with clinical findings, the three commonest joints affected by OD in the past were the knee, elbow and ankle, although it has been found to affect nearly every joint of the skeleton. On the other hand, the prevalence of OD in bioarchaeology appears to be higher compared with that reported by clinicians. The fact that the condition can be completely asymptomatic and undergo spontaneous healing may account for the discrepancy between these fields.

With regard to classification of the location or developmental stages of the lesion, bioarchaeologists have not attempted to produce any classification system, nor to adopt one from clinical studies. As clinical studies are based on observation of radiographs, and designed specifically for living patients, their application to skeletal samples is problematic.

(ii) Osteochondritis dissecans and palaeodemography

In relation to prevalence, there are no palaeoepidemiological studies undertaken on OD that can be compared to clinical studies. However, according to Rogers (1997) the frequency and distribution of OD in bioarchaeology do not seem to differ significantly from that seen in living populations. A number of studies, nonetheless, provide crude prevalence rates such as that of Schultz (1981), who found that 14.1% of the skeletal population from Kleinlangheim, Germany suffered from the condition. Arabaolaza *et al.* (2007) found a prevalence of 2.6% (4/150) in a skeletal sample from the Victorian site of St. Peter's Collegiate Church, Wolverhampton (UK), similar to the 2.7% found by Brickley (2006:130) at the contemporary site of St. Martin's, Birmingham (UK). Roberts and Cox (2003:151,209) reported a crude prevalence of 0.2% of during the Roman period in England with an increase to 1.5% in the early medieval period. Wells (1974) concludes that OD can be very common in some British skeletal samples accounting for 5% of individuals in certain cemeteries.

In relation to age of occurrence, it was indicated in section 2.5.5 that OD is, in general terms, a condition of the immature skeleton but, when archaeologists assess the age at death of skeletal remains, they cannot assess the age at which the condition occurred. Thus, mature adult individuals presenting OD lesions could have lived with the condition from childhood without leaving skeletal traces of the moment this event took place.

In relation to sex differences, the large majority of the bioarchaeological studies (Loveland *et al.*, 1984; During *et al.*, 1994; Stirland, 1996; Anderson, 2000, 2001; Brickley, 2006:130) support the clinical findings discussed in section 2.5.5 that OD affects males more than females. Exceptions to this rule are the papers of Schultz (1981) and Arabaolaza *et al.* (2007) where an equal number of men and women affected by OD were found.

With regard to aetiology, in general terms it can be said that bioarchaeologists tend to support a traumatic aetiology for OD. This is evidenced by the fact that it is often found under "trauma" in skeletal studies (Knüsel, 2000:116; Roberts and Manchester, 2005:121; Brickley, 2006:130; Arabaolaza *et al.*, 2007). A number of case studies (Loveland *et al.*, 1984; Stirland, 1996; Anderson, 2000, 2001) also believe that trauma, physical activity or occupation contributed to triggering OD in their specific cases. However, authors such as Aufderheide and Rodríguez-Martín (1998), Roberts and Cox (2003:33), and Ortner (2003:343) described the condition under circulatory disturbances leaving the door open for alternative aetiological contributions.

(iii) Osteochondritis dissecans and activity

In relation to physical activity and occupation, a few authors have ventured to correlate specific activities with osteochondritic lesions. During *et al.* (1994), for instance, associated the presence of OD at the distal end of both humeri in a skeleton with that of the presumed helmsman (found in the helm area near the steering mechanism of the sunken Swedish warship). The authors combined pathological, historical and archaeological data to associate the disorder with the hard manual labour involved in operating a large sailing vessel. On the other hand, Stirland (1991:45), who also worked with skeletal remains from a sunken (English) warship, the Mary Rose, showed scepticism about the possibility of relating the presence of osteochondritic changes among the crew with specific occupations. Wells (1974) suggested that, as OD was more often found during the Romano-British and Anglo-Saxon periods rather than in Bronze Age populations, the former groups settled in areas where the land had to be cleared for agriculture and that the land was prepared using poorly designed and inefficient equipment and/or wearing poor footwear, contributing to OD. He concluded that under these circumstances, injuries of the feet and ankle as a result of bruising, twisting and jarring could have damaged the cartilage of these joints leaving OD as a consequence of these activities. On the other hand, the low frequency of OD during the Bronze Age led Wells (1974) to suggest that the primary activity of these people was pastoralism. This way of life would have probably involved more leisure time as these people were committed to grazing their flocks and therefore imposed little strain on their feet. Osteochondritic changes observed in the wrists joint could have, according to Wells (1974), resulted from sudden twisting and turning of the hand from trying to plough rocky and hard soil, or to control restless farm animals. Knüsel (2000:116) suggested that the osteochondritic lesions found on both tibial plateaus in the Towton skeleton could have resulted from military activity, although he did not deny the possibility of it developing as a consequence of previous injury. More general patterns of activities causing OD are mentioned by Loveland *et al.* (1984) where activities of agricultural life in the Plains Indians, particularly if practised by individuals during a period of rapid growth, may have contributed to the presence of OD in this site. Rogers (1997) correlated the high prevalence of OD in the knee in skeletons of American Indians with hyperflexion of the knees, resulting from kneeling or squatting.

Finally, in a number of studies (Schultz, 1981; Brickley, 2006:130) OD of the elbow was more commonly found in the right arm. A clinical case of OD of the shoulder was also found in the dominant limb (Debeer and Brys, 2005). According to Brickley (2006:130) the side difference may represent the mechanical stress exerted upon the arm as a consequence of the type of occupation or activity performed from a young age. The premise of upper limb asymmetry being linked with the dominant use of one arm over the other, giving most humans a right-handed dominancy, has been supported by osteometric studies (Čuk *et al.,* 2001; Auerbach and Ruff, 2006), bilateral patterning of osteoarthritis and os acromiale (Bridges, 1992; Stirland, 1996).

2.5.8 Limitations and future research

Some of the limitations in the study of OD are described above and relate to the difficulty of differentiating this condition from others of a similar appearance. Rogers and Waldron (1995:28) believe that OD is probably over-diagnosed because other lesions such as small pits seen in concave surfaces of the joints, but of a different aetiology, can resemble those found in OD. Future development needs to involve creating diagnostic criteria to differentiate OD from other similar pathological conditions so that the condition is not over-diagnosed or underestimated. A few attempts have been made, such as that proposed by Birkett (1982) and Loveland *et al.* (1984), although no evidence of their adoption or application has been found in bioarchaeology.

2.6 Osteometric analysis

Contrary to previous sections that dealt with pathological or developmental conditions, this section will follow a different organisation. It will review the variables that affect the external dimensions of bones, paying particular attention to the contribution of osteometry to the reconstruction of activity patterns in human skeletal remains. In addition, particular consideration will be given to robusticity as this has been linked with general patterns of physical activity. Finally, there will also be a discussion of a number of bioarchaeological cases from which activity patterns have been interpreted.

2.6.1 Introduction

(i) Wolff's Law

The idea of analysing activity patterns using cranial and post-cranial measurements of bones comes from mathematical studies and mechanical principles formulated in the 19th century by Julius Wolff, an influential German orthopaedic surgeon. The so-called "Wolff's Law" is often used to describe how bones respond to mechanical stimuli by remodelling their internal and external structure in the direction of the functional stress (Pearson and Lieberman, 2004; Ruff *et al*., 2006). In other words, bones adapt and adjust their size and shape in response to external forces by depositing or resorbing bone tissue according to the mechanical demand (Larsen 1984:195-6). Having this in mind, it is understood that the mechanical adaptation of bones occurs under increased physical activity and muscles pulling in order to reduce the strain. On the other hand, decreased stress and unloading as a consequence of inactivity leads to the resorption of bone tissue, which then again restores the original strain levels (Ruff *et al.*, 2006).

A large number of studies support Wolff's hypothesis and the influence of physical activity and exercise over the bone structure. Clinical and sports science studies have shown that long-term involvement in intensive physical activities and sports can contribute not only to produce external hypertrophy of bones and muscles but also to an increase in bone mass and bone mineral density. The studies of Karlsson *et al.* (1995)

with weight lifters, Ducher *et al.* (2006) with tennis players and Calbet *et al.* (2001) with football players are evidence of this concept. Experimental studies using laboratory dogs (Barbier and Schepers, 1997) and rats (Warner *et al*., 2006; Zhang *et al*., 2006) have also remarked on how the skeleton modifies under different loading regimes. Conversely, the lack of activity or normal loading due to a variety of causes such as long periods of bed rest, weightlessness in space flight or absence of gravitational loading, or partial or complete immobilisation of limbs, results in decreased bone mass (LeBlanc *et al.*, 2007). A similar effect has been found in muscles and tendons (Yasuda and Hayashi, 1999).

Although physical activity, occupation and lifestyle are strongly linked with changes in bone morphology and bone dimensions, there are a number of important variables that can also contribute to modify the structure of bones. They will be summarised as follows:

(ii) Age effects

One of the best documented effects on changes in bone architecture is age. The clinical evidence is rich in examples where bone architectural changes in the form of bone hypertrophy, gaining bone mass and mineral density, are associated with physical activity commencing before puberty. For instance, Calbet *et al*. (2001) found that long-term sport participation starting at prepubertal age promoted an osteogenic response at the femoral neck and lumbar spine regions in football players. Similarly, Vicente-Rodriguez *et al.* (2005) worked with schoolchildren and found that long term sport participation resulted in an increment of femoral mass and density. In the upper limb, the study of Ducher *et al*. (2006) showed that playing tennis during the growing period was associated with an increment of the trabecular and cortical bone at the distal radius. They also emphasised that prolonging tennis into adulthood was associated with gaining further bone mass at diaphyseal skeletal sites. Studies carried out with adult men, such as that of Karlsson *et al*. (1995), have also shown that professional weight lifters have increased bone formation and size than adults who are relatively sedentary. On the other hand, when ex-weight lifters who had retired from competitive training were compared with sedentary gender matched controls, it was found that bone formation and bone mineral density did not differ between the two groups. These results contradict those obtained by Uzunca *et al*. (2005) who compared ex professional footballers with non-athletic controls and found that the former group exhibited higher bone mineral density at different skeletal regions than the controls.

The effects of age on bone morphology are difficult to understand if a number of other potentially influencing factors of bone morphology are considered, such as the age at which play began and ceased, the frequency and number of years played as well as the type of loading and strain, bone element involved or even the site within the element.

(iii) Sex effects

As with age, sex is another well-documented factor influencing bone geometry. Comparative studies aimed at addressing sex-related changes in bone density and bone geometry between the sexes have shown that women exhibit a decline in bone mineral density and a faster rate of endosteal expansion compared with men (Kaptoge *et al*., 2003; Lauretani *et al*., 2008). The former authors took a series of measurements of the hip in a population of 1,511 men and women aged 65+ from Norfolk, UK and the latter analysed the right tibia in 1,173 participants from the Italian towns of Greve and Bagno. Both studies found that women showed signs of gradual decline in bone apposition with age particularly after the age of 65 years. Furthermore, women exhibited significantly more age-related medullary expansion at the femoral neck and hip (Kaptoge *et al.*, 2003) and at the tibia (Lauretani *et al.*, 2008) than men. This expression of endocortical resoption is associated with endocortical bone loss, a phenomenon according to the authors, linked with greater fragility, fracture risk and osteoporosis. This apparent disadvantage has been explained through differences in endocrine factors, particularly the levels of circulating oestrogen. Longitudinal studies have shown that, after the menopause, women exhibited a significant decrease in bone density and an increment in trabecular spacing compared with their eumenorrhoeic years (Akhter *et al*., 2007). In women athletes, amenorrhea has been found to have an impact on bone turnover and bone formation (Zanker and Swaine, 1998).

(iv) Diet and disease effects

Poor nutrition and infection usually go hand in hand as responsible factors for changes in bone architecture. In developing countries food availability varies according to social status and economic resources and, for this reason, those who are economically disadvantaged, particularly juveniles suffering from chronic nutritional deficiencies and infection, will be prone to exhibit poor bone status and growth retardation (Larsen, 1997:8-9, 61). For instance, in Argentina, Oyhenart *et al*. (2007) worked with schoolchildren from a poor district outside Buenos Aires and found that their adverse living conditions were detrimental to their skeletal health and wellbeing as they showed delay in growth (low height-for-age) and under nutrition (low weight-for-age) when compared with the reference population. In Great Britain, Davies *et al.* (1999) observed that vitamin D supplement intake was dependant on seasonality and social status of preschool children. Low intake of this vitamin is associated with poor bone quality and rickets, a bowing deformity of the long bones. The authors suggested that, in order to minimise the risk of poor bone health, children living in deprived areas of northern England and Scotland should increase their levels of vitamin D supplements during the winter months, when the lack of sunlight exposure and the chances of synthesis are minimal. Similarly, in rural Gambia, Munday *et al.* (2006) observed that during the months when environmental conditions were poor and the food supply decreased, pre-pubertal boys showed an increase in the prevalence of infections and a concomitant reduction in bone turnover and skeletal growth. Experimental studies using laboratory rats, such as that of Lobe *et al.* (2006), where environmental conditions have been adversely induced, have also showed that the young generation of malnourished rats exhibited a comparatively small skeletal size in adulthood and a slower cranial growth when compared with controls.

According to Larsen (1997:61) the chances of showing morphological changes in bones due to nutritional or diseased effects during adulthood are rare. This is because the human skeleton is more sensitive and vulnerable during the years of growth and development of early childhood. However, a study performed by Shatrugna *et al*. (2005) with adult Indian women from low-income groups has shown that an inadequate calorie and protein intake can cause a reduction of bone mineral density and bone tissue, putting them at risk of developing osteoporosis.

Bone architecture can also be altered when associated with OA. For instance it has been found that continued osteoblastic activity throughout life leads to higher bone density. In such individuals the risk of OA might increase. The study conducted by Hochberg *et al.* (2004) supports this idea as they observed that a higher bone mass played a role in the development of radiographically diagnose OA of the knee among American adults. On the other hand, an inverse association is commonly the case between OA and osteoporosis. El-Sherif *et al*. (2008) found that the bone mineral content and the bone mineral density of osteoarthritic hands of postmenopausal women were significantly reduced when compared to controls.

To summarise, it is important to recognise that physical activity is only one of a large number of contributory factors to changes in the structure of bones. Being aware of the possible influence of these factors is an important key point in avoiding over simplistic assumptions, i.e. that the external morphology of bones is only determined by and the consequence of physical activity and occupation. According to Ruff *et al.* (2006) in order to reconstruct behaviour, it is necessary that any morphological study should carefully consider such evidence and its implications.

2.6.2 Osteometric analysis in bioarchaeology

Osteometry is an important tool for recording human variation. Its value lies in the potential to perform morphological and comparative studies within and between populations. Although the skull has been the major focus of interest for more than three centuries, the post-cranial skeleton has also provided a wealth of measurements with which to assess stature, sex, age and also activity patterns (Buikstra and Ubelaker, 1994:69). The measurement of external bone dimensions such as lengths, breadths, diameters and circumferences is a method often employed to record intra and inter population variations as well as to reconstruct activity. Techniques to measure external diaphyses of bones include tape measures, osteometric boards and electronic callipers

(Knüsel, 2007:105). Another method worthy of mention is cross-sectional geometry. This is, according to Jurmain (1999:231), the most original approach to exploring activity in bioarchaeological studies. Using biomechanical and engineering principles, the investigations derived from these studies have gained particular impetus after the contribution of Ruff and co-workers. The purpose of this research is to infer the response of long bones to increasing loading, physical activity and behavioural patterns through the analysis of their geometrical properties (Larsen, 1997:197-8, 2002; Jurmain, 1999:231; Stock and Pffeifer, 2004; Ruff *et al*., 2006; Wanner *et al*., 2007; Ruff, 2008). The measurement of geometric properties is taken perpendicular to the axis of the chosen long bone in order to quantify the proportion and distribution of skeletal tissue in a section (Larsen, 1997:199). Measurement includes direct sections of bones or non-invasive imaging such as standard biplanar radiography, CT scans and photon absorptiometry (Larsen, 1997:202; Jurmain, 1999:248).

Both methods have been employed to address similar research questions such as variations between and within populations through changes in subsistence strategies (e.g., Bridges, 1989b; Larsen *et al*., 2007), temporal trends in robusticity patterns (e.g., Larsen, 1981; Ruff *et al*., 1993; Jacobs, 1993), sexual dimorphism (e.g., Ruff, 1987; Mays, 1999) and bilateral asymmetry (e.g., Stirland, 1993). However, in recent years cross-sectional geometry has been preferred over external bone dimensions despite the fact that a large available database on external bone dimensions allows a more complete record of human variation than is possible from cross-sectional geometry. The reason for this selection is, according to Larsen (1997:225), due to the fact that external bone dimensions only provide a fragmented or limited picture of the effects of loading over the skeleton. They do not offer thorough details of the architectural properties of long bones nor provide information about the way the bone tissue is distributed in a section (Larsen, 1997:223,225; 2000:89). On the other hand, the studies of Knüsel (2007:110) and Stock and Shaw (2007) where both methods were combined have shown that external bone dimensions and cross-sectional geometry effectively provide reasonable correlations and comparable results. Stock and Shaw (2007) have also emphasised that, although radiographic imaging provides the best means of data collection, in the absence of CT scanners or direct sectioning, a high level of accuracy can be achieved from external bone measurements. For this reason, studies coming from both methodological approaches will be discussed here, but particular attention will be given to external bone measurements as this is the method chosen for exploring general patterns of activities between both samples of Amerindians from northern Chile in this study. This was viewed as the best available approach in terms of practicality, convenience, amount of time available to perform the analysis, and the prohibitive costs involved in any alternative method.

(i) Robusticity

A number of external bone measurements have been employed to calculate various cranial and postcranial indices as well as to answer specific questions. Of particular interest due to the objectives of this thesis is the robusticity index, which is a measurement of the dimensions or proportions of a human bone (Knüsel, 2007:104). Skeletal robusticity is a reflection of the strength observed in the size and shape of bones (Stock and Shaw, 2007) and also of the apposition of bone tissue (Stock and Pfeiffer, 2004). This is believed to be a response to elevated mechanical loading (Ruff *et al.*, 1993). Upper and lower limb bones, particularly the humerus, femur and tibia, have been equally used to investigate robusticity patterns. However, as the lower limb bones are involved in bipedal locomotion, they have also been employed to analyse patterns of mobility. Upper limb bones, on the other hand, are involved in a wider variety of non ambulatory activities and therefore they have also been used to analyse asymmetries (e.g. Stirland, 1993) and patterns of handedness (Steele, 2000). As humans use their upper limbs to perform manual activities, differences in upper limb robusticity between groups are more likely to result from differences in habitual behaviour (Larsen, 1997:210; Knüsel, 2007:104).

A number of robusticity indices have been employed to answer specific questions in bioarchaeology, for instance temporal trends of robusticity patterns encompassing the entire record of human evolution. Ruff *et al.* (1993) found that there has been a marked reduction in human skeletal robusticity through time from fossil hominids to modern humans. The authors found decreased robusticity in the femoral midshaft strength from

the early Pleistocene within the *Homo* genus to recent humans, which they interpreted as mainly due to a decline in mechanical loading of the skeleton.
Temporal trends in humeral robusticity have shown similar patterns to those observed for the postcranial skeleton (Ruff *et al*., 1993; Fischman, 1995).

A similar temporal trend has also been found in the transition from hunter gathering to agriculture. In a number of cases (Larsen and Ruff, 1991, 1994; Ruff *et al*., 1984; Larsen *et al*., 2007) it has been found that, with the adoption of agriculture, both males and females from Florida and the Georgia Bight area (USA) experienced a decline in the size of subtrochanteric and midshaft femoral sections and the mid-distal section of the humerus. According to ethnographic accounts, these historical populations became compulsorily sedentary because they were forced to live around the mission centres. However, the arrival of new circumstances and demands related to missionisation were important contributing factors to the increment of body size and robusticity. Larsen (1981, 1984) also worked with skeletal remains from the prehistoric Georgia coast but utilised external bone measurements such as lengths, circumferences and diameters of the femora, tibiae and humeri. The author found a significant decrease in skeletal robusticity from the pre-agricultural coastal hunter-gatherers relative to the agricultural groups from prehistoric Georgia. This trend was particularly accentuated in females than males probably because the former group may have been subjected to less mechanically demanding activities than males after the adoption of the agricultural lifestyle. Similar patterns as those observed in the Georgia Bight were described by Brock and Ruff (1988) where the femoral midshaft diameter of males from the American southwest, exhibited a pattern of decline in mechanical demand from earliest to later agricultural periods. The authors interpreted these findings as being consistent with the archaeological interpretations of increasing sedentism with the shift to agricultural intensification. Contrary to this trend, Bridges (1991b) found greater robusticity in femoral and humeral cross-sectional geometry in agriculturalists from north-western Alabama than in earlier foraging populations. The author therefore suggested that the adoption of an agricultural lifestyle in both adult males and females involved more strenuous physical activity than in the archaic foragers.

In the Old World the shift from foraging to farming also led to a variation in the patterns of robusticity. Jacobs (1993) for instance, observed an increment in the robusticity indices of the humerus and femur in both male and female Ukrainian samples from the Neolithic, relative to Mesolithic samples. The author interpreted these findings as resulting from the strength involved in intensive food production and the concomitant sedentism. Similar results were obtained by Marchi *et al.* (2006). These authors compared upper Palaeolithic hunter-gatherers with Neolithic agriculturalists from Liguria, Italy and observed an increment of humeral robusticity in males, but not in females, with a reduction in bilateral asymmetry. Cross-sections of the femur also revealed an increment from the early periods to agriculture in males, with a steady decrease over time in females. In conclusion, the transition to Neolithic economies did not reduce functional requirements in Ligurian males, as observed in the New World samples.

Skeletal robusticity has also been employed, as mentioned earlier, to bring light to mobility patterns. As the lower limbs are associated with bipedal and ambulatory activities, studies of mobility patterns have focused their analysis particularly on the femur and the tibia. For instance, according to Ruff (1987) lower limb robusticity has been linked with terrestrial mobility. He analysed the femora and tibiae of both males and females from the Middle Palaeolithic extending to modern times and observed a consistent decline in the antero-posterior bending properties compared with medio-lateral bending properties of these bones. Ruff interpreted these findings as resulting from a decline in mobility and less frequent walking or running over uneven surfaces. In line with these findings, Stock (2006) analysed robusticity and mobility patterns among different groups of hunter gatherers and also found that the strongest correspondence with terrestrial mobility was observed in measurements taken at the femoral midshaft. On the other hand, according to Bridges (1989b) and Carlson *et al.* (2007), elevated postcranial robusticity does not always characterise mobile hunter-gatherer groups. The former author found that archaic hunter-gatherers displayed greater size and strength in long bones than Mississippian agriculturalists suggesting that sedentism involved more structural changes than those experienced by mobile populations. The latter authors analysed modern hunter-gatherers from Australia and compared them with three other populations with different subsistence economy and mobility patterns: the Khoi-San foragers, agricultural-industrialised Zulus and industrialised African Americans. The Australian sample showed an overall reduced post-cranial robusticity at nearly all midshaft locations, demonstrating that this attribute does not always represent these populations.

(ii) Robusticity and activity

The bioarchaeological literature linking robusticity patterns, external bone dimensions or cross-sectional analysis with activity is not abundant. In addition, the available data comes almost entirely from the upper limbs. In men, for instance, asymmetric robusticity of the upper limbs has been interpreted predominantly as the result of weapon use. Activities such as archery have been correlated with hypertrophy of the left elbow in individuals who fought the battle of Towton AD 1461 (Knüsel, 2007) and among the crew of the Mary Rose, a sunken flagship dating from AD 1545 (Stirland, 1993). In the New World, and in line with these findings, Bridges (1989b) found an increase in the left forearm dimensions of prehistoric Mississippian males that the author related to the use of the bow. Stock and Pfeiffer (2004) compared robusticity in the upper limbs of Later Stone Age foragers from the forest and the fynbos biomes of southern African Cape region and found behavioural differences between the men of these biomes. Bilateral asymmetry among the former group of males was attributed to a greater dependence on hunting using spears and bows.

Females on the other hand, have been found to be more symmetrical than males in their upper limb morphology. For this reason a number of authors such as Bridges (1989b) correlated the considerable bilateral hypertrophy found among the prehistoric females from the Southeastern Unites States with activities such as food processing, particularly corn using pestles and mortars. Wanner *et al.* (2007) also found remarkably symmetric upper limbs among the coastal Maya females of Xcambó in Yucatan, Mexico. These authors were also inclined to interpret these findings as resulting from grinding grain and seeds. In line with these studies, Stock and Pfeiffer (2004) also correlated the bilateral symmetry found in the upper limb of the Later Stone Age females from the forest and fynbos biomes of South Africa with processing seeds or ochre with mortars and pestles. They did not deny the possible contribution from other activities such as shellfish harvesting or tuber digging, but they also recognised the difficulty in differentiating the relative contribution of these activities or specific activities to the ultimate morphological findings. These explanations provide, according to Jurmain, (1999:254, 265), a very seductive reasoning which is only based on speculation and usually constructed as the “best fit” explanation. Even though the attempt from many archaeologists to substantiate and support their findings using known ethnographical analogy, it does not provide additional support unless more attention is given to clinical investigations, particularly those involving young athletes.

With regard to the lower limbs, Marchi *et al.* (2006) suggested that the increment in antero-posterior robusticity in the femora of Neolithic groups from northern Liguria, Italy, compared with Mesolithic populations, was due to the hilly and mountainous territory in which their pastoral-based mobile subsistence took place. Other patterns of activity such as that presented by Stock (2006) also support the correlation between terrestrial mobility among different groups of hunter-gatherers, particularly when femoral midshaft diameters of males are considered. On the other hand, Jurmain (1999:254) criticised the assumption that only certain activities associated with terrestrial hunting or mobility would have produced such morphological changes as, in essence, a number of activities could have produced similar bone manifestations.

To summarise, the number of activities linked with the lower limb bones is remarkably small compared to the upper limbs. This is, as stated earlier, because the former group tend to reflect the physical demands imposed by locomotion which are more uniform and symmetric, whereas the latter is related to volitional activities. In this respect, Ruff *et al.* (1993) suggested that lower limb robusticity provides biased data compared to that for the upper limbs, as in humans it is part of the locomotor system and not part of the ambulatory activities. Furthermore, the differences observed in the robusticity patterns of the upper limbs between males and females can be a response to a social division of labour as males have been found to be more asymmetrical than females.

2.6.3 Limitations and future research

Some of the limitations to future research within this field have been discussed in the introduction to this section (see 2.6.1) and are related to the lack of awareness of the potential influence of systemic factors on the final structure of bones. Besides physical activity and mechanical loading, there are a number of intrinsic and extrinsic factors that can potentially influence bone geometry. Regretfully, only a few bioarchaeologists (Ruff *et al*., 1984; Bridges, 1989b; Jurmain, 1999:258; Wanner *et al.*, 2007) have recognised their importance or assessed their effects in skeletal samples. Jurmain (1999:257-9) for example, recognised that the limitations observed in the study of physical activity and occupation by performing osteometric analysis do not differ from those already seen in previous sections (see 2.1, 2.2) with the study of enthesophytes, osteoarthritis and other skeletal markers (1999:248). In addition, Jurmain (1999: 253-4, 265) has emphatically expressed his worry regarding the interpretation of bone measurements with specific activities and occupations as those mentioned above, particularly in view of the spectrum of possible activities performed in the past. On the other hand, he has also highlighted that once the reliability of geometric measurements of bones is confirmed and well-established, then they could become the best tool available to bioarchaeologists for reconstructing patterns of activity from skeletal remains (Jurmain, 1999:259).

Future research in osteometry should aim, according to Jurmain (1999:259), to produce collaborative studies with clinical colleagues to substantiate the utility of this innovative approach. Furthermore, Jurmain (1999:239) also recognises that in order to extrapolate activity patterns from human skeletal remains, future research should aim to analyse contemporary samples from which activity patterns are known. Similarly, Stirland (1993) suggests that specific activities can only be assessed when the occupation or history of the individuals is already known. However, this is not always possible, particularly when considering the variety of activities practised through time and their variance among populations.

Recent innovative attempts have been made in microscopy to attempt to provide a new approach to the study of activity patterns. Pfeiffer *et al*. (2006) tested the relationship between secondary osteon and Haversian area measurements and physical activity but regretfully it was concluded that they could not be used to reconstruct aspects of behaviour among past populations.

This chapter has reviewed how clinicians and bioarchaeologists interpret MOS. It has also highlighted how bioarchaeologists have used these MOS to interpret physical activity. The next chapter will look at the archaeological background of the skeletal sample, and will summarise what is known about their subsistence economy, diet and lifestyle. Finally it will look at the methods used in this study to analyse the MOS.

Chapter 3:

Materials

Chapter 3: Materials

In this section information is provided regarding the context in which the skeletons that comprise the sample of study were found. Relevant environmental information regarding northern Chile is also outlined because this has played an important role in determining the contrasting subsistence economies practised by these individuals, from which potential "activity-related" skeletal markers could be identified. Finally, the main criteria for choosing the samples will be summarised.

3.1 Historical and archaeological background to the samples

The skeletal material analysed for the purpose of this study is curated at the Laboratorio de Antropología Física (Laboratory of Physical Anthropology), Museo Arqueológico San Miguel de Azapa (MASMA), (Archaeological Museum of San Miguel de Azapa) Universidad de Tarapacá, in Arica, Northern Chile (Fig 15).

The skeletons analysed in this study were mummified remains of two types. Some of them were naturally mummified by the environment and others were artificially mummified. They were excavated during the late 1970's and early 1980's by a number of Chilean and international archaeologists including Percy Dauelsberg, Guillermo Focacci, Dr Colagero Santoro, Dr Ivan Muñoz, Dr Bernardo Arriaza, and Dr Vivien Standen (all from the University of Tarapacá, Chile), and Dr Marvin Allison (Virginia Commonwealth University Service, USA). Approximately 900 bodies were sent after excavation to the Laboratorio de Antropología Física for analysis, conservation and storage. Due to the huge amount of work required to deflesh the bodies for the purpose of osteological analysis, and in addition to new conservation trends adopted at the Museo Arqueológico San Miguel de Azapa aimed at preserving the bodies as they were found, only half of those unearthed were skeletonised and disarticulated. The other half was left curated today in the Museum as they were originally found in their mummified form (Aufderheide, 2003) (Fig 16).

Figure 15: Location of Arica city

Figure 16: Mummy of an inland agriculturalist (non-catalogued).
Photo by Paola Ponce

To understand why this area is so abundant in well-preserved mummified human remains, it is necessary to take into consideration some of the physical, geographical, and environmental aspects of this region.

In geographical terms, Arica is located in the Atacama Desert, a region of extreme aridity, which extends from a latitude of 18° to 30° South (Arriaza *et al*., 2008). With stable mild temperatures throughout the year ranging from 12°-22°C, the unparalleled weather conditions of this desert, considered one of the driest on Earth, are owed largely to the combined influence of its proximity to the Pacific Ocean, the Andean cordillera that runs parallel to the coast (Fig 17) and the Humboldt oceanic current that brings cold waters and cool dry winds north from the Antarctic. Precipitation at coastal sites in Northern Chile is almost non-existent and the pattern observed today has remained unaltered over the last 10,000 years according to palaeoclimatic studies (Ramírez de Bryson *et al*., 2001). In contrast, precipitation is noticeable above 2,500m above sea level, where a small amount of moisture condenses sufficiently to fall as rain or to remain deposited as snow on the highest peaks (Fig 18).

Figure 17: View of the Andean cordillera running parallel to the coast outside the city of Arica, northern Chile. Photo by Paola Ponce

According to Aufderheide (2003) the unique characteristics of the Atacama Desert, combined with the almost total absence of groundwater and possibly the high nitrate content of the sandy soil, may have all contributed to the removal of water from the burial contexts and facilitated the natural preservation of human mummies over a long time span.

Figure 18: Highest peaks of the Chilean Altiplano near the Bolivian border.

Photo by Paola Ponce

The skeletal sample analysed was recovered from a number of cemeteries belonging to two distinctive groups, the “coastal fishers” and the “inland agriculturalists”. The former group of skeletons belonged to the 3rd -2nd millennium BC (Archaic period of northern Chile), and the latter belonged to the 1st millennium AD (Middle and Late Intermediate periods of northern Chile) (Table 8).

Cultural period	Dates	Time period
Early Chinchorro	7000 BC - 5000 BC	Archaic
Mid Chinchorro	4900 BC -1600 BC	Archaic
Late Chinchorro	1500 BC – 1000 BC	Archaic
Alto Ramírez	1000 BC - 350 AD	Formative
Cabuza	400 - 1000 AD	Middle
Maitas Chiribaya	1100 - 1300 AD	Middle
San Miguel	1300 - 1450 AD	Late intermediate
Inca	1450 - 1550 AD	Late
Colonial	1550 - 1824 AD	Modern

Table 8: Chronology of occupation of northern Chile

The following sections 3.2 and 3.3 provide further information about these populations, their subsistence economy, diet, and funerary practices, which are essential to understand their lifestyle.

3.2 The coastal fishers

The coastal sample encompasses a group of individuals buried at the cemetery sites of Morro1 (Mo1), Morro1-5 (Mo1/5), Morro1-6 (Mo1-6) and Quiani7 (Qui-7) (Fig 19). These Chinchorro samples date to the 3rd-2nd millennium BC (Allison *et al*., 1984; Focacci and Chacón, 1989; Guillén, 1992; Arriaza, 1995a; Standen, 2003). They belong to the so-called Chinchorro people. This name was given to these individuals by the influential German archaeologist Max Uhle, who unearthed the first bodies at the beginning of the twentieth century near today's Chinchorro beach outside the city of Arica (Arriaza, 1995a). For the remainder of this study, the term "coastal fishers" and "Chinchorro" will be used interchangeably as these can be considered synonyms.

The Chinchorro settled along the Atacama coast between latitude 23° and 27° south, expanding their cultural influence geographically along the Pacific coast for approximately 1,500km, from Ilo in Southern Peru to Antofagasta in Northern Chile (Arriaza, 1994, 1995a; Aufderheide *et al*., 1993; Aufderheide, 2003). Despite the adverse environmental conditions of the Atacama Desert, settlement in this region was possible thanks to the presence of small rivers carrying run-off water from the highland rain and snowmelt, which cut through the desert at widespread intervals forming narrow gorges all draining into the Pacific Ocean. The presence of patchy oases with plants and wildlife associated with these small rivers, and there being adjacent to the coast would have provided a number of valuable raw materials (plants, birds, eggs, river shrimp, etc) as well as fresh water resources. In addition to the above, diverse and rich marine fauna including fish, molluscs, marine birds and sea mammals available all year round from the Pacific Ocean would have allowed early archaic populations to survive and settle down (Guillén, 1997; Arriaza *et al*., 2008).

The archaeological presence of coastal fishers is limited to the archaic period (Table 8). The term "archaic" in the south-central Andes is generally used to refer to the pre-ceramic period, a time frame spanning approximately between 8,000 BC - 1,000 BC (Wise *et al*., 1994). Within this period, coastal Chinchorros settled down uninterruptedly on the Chilean coast prior to European contact from 7,000-1,500 BC, and their lifestyle remained practically the same for over five millennia (Arriaza, 1995a). Evidence to support this assumption comes from the consistent use of the same tool technology, the use of formal cemeteries with unchanged mortuary practices as well as the presence at all time periods of external auditory exostoses, an “activity-related” condition believed to be a response to exposure to cold water as a result of diving and swimming to gather seafood (Aufderheide *et al*., 1993; Arriaza 1995a; Standen *et al*., 1995).

The Chinchorro were an archaic population characterised by the absence of sophisticated technology; they did not produce pottery, have developed smelting techniques for metals, or use loom-woven textiles. However, they performed unrivalled mummification techniques and practised a unique funerary cult for the dead that cannot compare with those of more developed complex societies (Focacci and Chacón, 1989; Standen, 1991; Arriaza, 1994, 1995a; Arriaza *et al*., 2005).
To evaluate the potential presence of “activity-related” skeletal changes among these populations, it is necessary to review what it is known about their subsistence economy and lifestyle. Assuming that the pursuit of food is a task that determines behaviour in past populations, particularly if this involves survival (Merbs, 1983; Arriaza, 1995a), the analysis of their subsistence economy can provide valuable information about their lifestyle. The next section will therefore examine the information known about this topic.

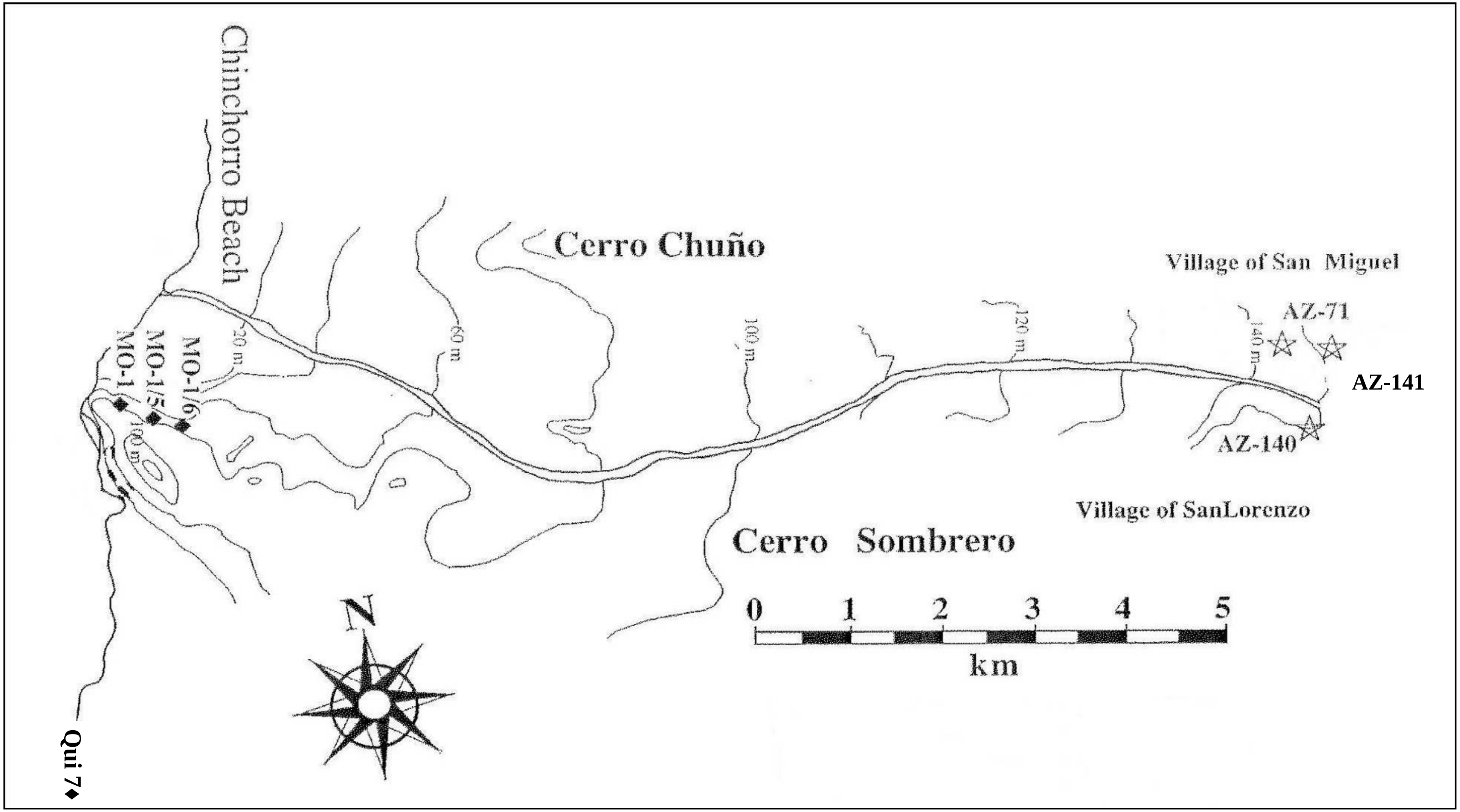


Figure 19: Location of the sites studied. Modified from Sutter and Mertz (2004: 133)
References: ♦ Coastal sites ☆ Inland sites

3.2.1 Subsistence economy, diet and lifestyle

The Chinchorro were, according to Alfonso *et al.* (2007), a population of semi-sedentary hunter-gatherer-fishers. According to Arriaza (1995a) the Chinchorro were a sedentary group of fishers highly dependent on the marine resources that their narrow ecological niche provided. He suggested that the practice of artificial mummification, seen from the point of view of the energy involved can only be interpreted in the context of a sedentary society. Nomadic or highly mobile societies tend to dispose of or abandon the bodies of their dead, whereas sedentary societies tend to develop cemeteries, as the Chinchorro did, thus reinforcing Arriaza's hypothesis. Secondly, the time and energy invested in preparing bodies for mummification would indicate that they were not meant to be transported or carried nor were they meant to be left behind if the group moved somewhere else. Thirdly, the significant effort involved in preparing bodies can only be explained if sufficient knowledge was available about acquiring the specific local plants and soils necessary to perform the mummification. He suggested that unlike hunter-gatherers, the presence of formal cemeteries and the time and energy invested in mummifying their dead indicates the presence of a sedentary population.

The analysis of Chinchorro diet based on the archaeological evidence suggests that they fished and gathered numerous marine products such as mackerel, sole, sardines, and manta ray, using for this purpose cactus needles (Fig 20) and various sizes of fishhooks made of shells (Fig 21) (Standen, 2003). Fishing lines were made of vegetable fibres; animal or human hair and stones were used as sinkers (Arriaza, 1995a; Standen, 2003).

Figure 21: Cactus needles used as fishhooks. Artefacts from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

Figure 20: Fishhook made of shell. Artefacts from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

The Chinchorro also gathered shellfish such as clams, mussels, limpets, and winkles, and marine plants such as seaweed. Consistent with this activity is the presence of large shell middens in a number of coastal sites (Arriaza *et al*., 2001; Standen, 2003; Standen *et al*., 2004; Aufderheide *et al*., 1993). To open bivalves and other molluscs, or to retrieve them from the rocks the Chinchorro probably used “chopes” (Fig 22), a specific type of tool made from the ribs of sea lions and camelids.

Figure 22: Chopes made of ribs of sea lions. Artefacts from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

As well as fishing, the Chinchorro also complemented their diet with hunting. The remains of marine fauna such as sea lions and dolphins in addition to shore birds such as pelicans and cormorants have been found at a number of Chinchorro sites (Focacci and Chacón, 1989; Standen, 2003). Various bi-products from the hunting of sea lions and dolphins such as harpoon heads for hunting, skins of sea lions for funerary bundles, as well as chopes have been excavated. Birds had had multiple uses too, not only for meat consumption, but also for their skins for funerary purposes, and their bones were used to make beakers, spatulas and various containers. The bones were probably also used in ceremonial mummification activities as scalpels (Standen, 2003). According to Arriaza (1995a) and Standen (2003), the presence of whale bones in Chinchorro cemeteries could indicate that, although probably not hunted, they were scavenged when they occasionally became stranded on the shore.

To a lesser extent, the Chinchorro also hunted terrestrial animals such as rodents, vicuñas and/or guanacos (small camelids indigenous to South America) and probably gathered terrestrial plants that the swampy coastal environment provided (Guillén, 1997 Arriaza *et al*., 2001). Terrestrial animals and plants only constituted 10-12% of the Chinchorro diet according to palaeodietary reconstruction, and marine resources (fish, sea lions, shellfish, etc) constituted about 80% of their diet (Auderheide *et al.*, 1993). The results of this predominantly marine diet are also supported with data from coprolite analysis. Parasites such as the marine tapeworm or *Diphyllobothrium pacificum* that normally cycle between marine fish and sea lions were found affecting these populations probably following the consumption of poorly cooked infested fish (Reinhard and Urban, 2003).

The presence of skeletal evidence of camelid bones is very poor and despite reaching the point of being nearly nonexistent in the majority of the Chinchorro sites, Standen *et al*. (2004) highlight the large number of items made from the skin, and fur from these animals. For instance, they were commonly used not only to stuff and artificially prepare the mummies, and to wrap up the body in a funerary bundle but the wool was also used to prepare a number of items including fishing lines, waist belts, pubic covers, loincloths and skirts (Fig 23), or to embroider reed nets. The imbalance between the evidence of camelid bones and the products derived from them led Standen *et al*. (2004) to raise the hypothesis that the Chinchorro people obtained raw material such as skins and fleece from trading with inland populations of the Andean plateau.

Figure 23: Skirt made of camelid wool. Artefact from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

The hunting equipment used by the Chinchorro comprised of a number of utensils (Fig 24) that, according to Arriaza (1995a), could have been used for hunting both marine and terrestrial animals. For instance, various types of projectiles including small bone harpoons with thorn barbs, bone and wooden harpoon heads and harpoons, with or without detachable heads containing a bone fragment or lanceolate lithic point, were reported at a number of Chinchorro sites (Focacci and Chacón (1989). Other important parts of the hunting tool kit were spears, throwing sticks and atlatls, sometimes with a hook carved in the wood or with thumb holders as well as darts and wooden knives (Fig 25) (Arriaza, 1995a; Standen, 2003).

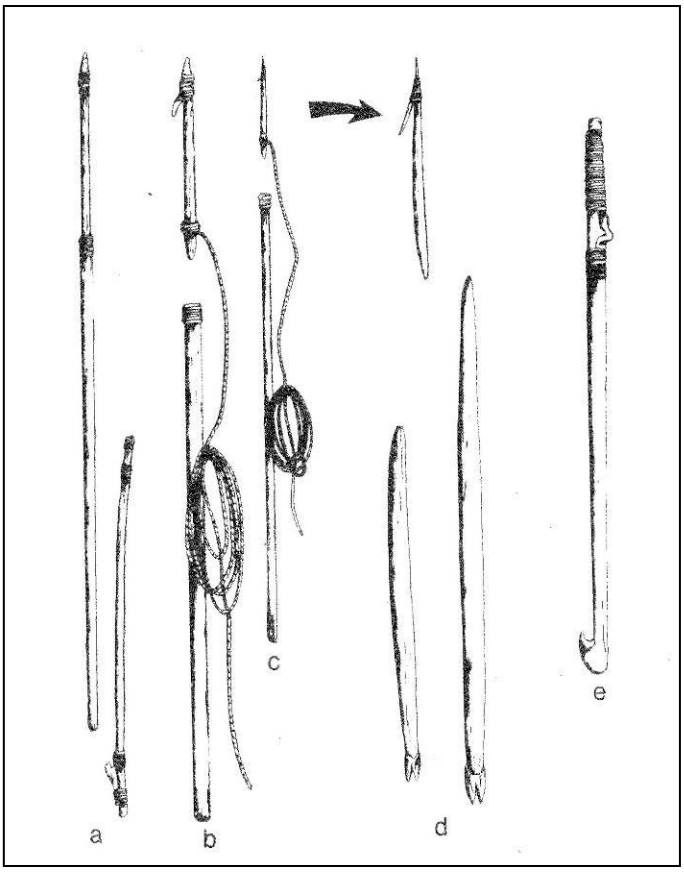


Figure 24: Hunting tools: (a) atlatl and throwing stick (b,c) harpoons and detachable points (d) two detachable harpoon heads without stone tips (e) atlatl with thumb holder. From Arriaza (1995a)

According to Arriaza (1995a) despite the simplicity of their fishing, harpooning and hunting technology, it is evident that it proved to be highly efficient as they are present in the archaeological record for thousands of years.

Figure 25: Wooden knife with lithic point. Artefact from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

Another aspect of the Chinchorro lifestyle, and a complementary activity to the above, is represented by their weaving work. Artefacts associated with the production of textiles are simple but tend to resemble those used by later populations such as the inland agriculturalists (section 3.3.1 of this chapter) or by modern Aymara populations from Bolivia (Standen, 1991, 2003). The weaving set comprised wooden bell-shaped spindle whorls with a central hole to introduce the spinning needles or “pushka” which were usually painted with ochre. Another item associated with this industry was the “vichuña”, a tool made of camelid bone with a sharpened end used to thread and tighten the wool used in the weaving process. Woven items include skirts made of camelid wool suspended from a waist cord (Fig 23). Small leather bags sewn with tendon strings were also made from camelid skin, usually for the purpose of storing mineral pigments such as manganese and iron oxide (Standen, 1991; 2003).

The weaving work also included preparing blankets made of twined totora reeds (Fig 26) that they probably gathered from areas adjacent to the river mouths (as they still are today). Totora mats of different sizes and thicknesses sometimes decorated with camelid wool or human hair and coloured in red, blue and black were used to wrap up the dead in a funerary bundle (Focacci and Chacón, 1989; Standen, 2003; Aufderheide, 2003), or were used for domestic purposes such as for sleeping or sitting on, or as roofing materials for their huts (Arriaza, 1995a; Arriaza *et al*., 2001).

Figure 26: Reed mat made of totora fibres. Artefact from Museo Arqueológico San Miguel de Azapa. Photo by Raúl Rocha

Brushes made with clumps of vegetable fibre or twigs, (Fig 27) sometimes wrapped with cords made of vegetable and/or animal/human hair, were also very popular items probably used to paint the artificially prepared mummies as well as to decorate the living (Arriaza, 1995a). Mesh net baskets made out of knitted vegetable fibres and animal tendons were also present in funerary contexts, and were probably used for collecting molluscs as well as for catching small fish (Aufderheide, 2003).

Figure 27: Paintbrush wrapped with vegetable cords. Artefact from Museo Arqueológico San Miguel de Azapa. Photo by Raúl Rocha

In summary, the Chinchorro subsistence economy and diet was primarily marine-based and, as such, it certainly would probably have involved a number of regular activities. On the basis of the grave goods found at the cemetery of Morro1 (molluscs, bones of fish, birds, marine mammals and camelids), Standen (2003) suggested that hunting was predominant and certainly occupied a great part of the Chinchorro existence in comparison with gathering and fishing. Complementary activities such as gathering vegetable fibre to produce a number of items for daily use, such as those described above, would also have been practised although with far less time investment.

Finally, the Chinchorro did not practice agriculture nor did they practice advanced technologies such as making ceramics or smelting metals, but they did perform unparalleled mummification techniques for their dead for which today they are known world-wide. A brief summary about this unrivalled activity will be given in the following section.

3.2.2 Funerary practice and grave goods

Most of the Chinchorro cemeteries were concentrated along the coastal areas of Arica. In general, although densely populated, they varied in size with some examples containing small numbers of individual burials whereas in others the numbers exceeded more than a hundred (Standen, 1991; Arriaza, 1995a). On numerous occasions the graves show evidence of post-mortem disturbance which is consistent with intercutting, superimposition and truncation of the graves due to the re-use of the funerary space (Focacci and Chacón, 1989).
A typical Chinchorro cemetery had bodies interred next to each other in an extended supine position with the arms to the sides, and without coffins in shallow graves directly dug into the sand (Fig 28).

Figure 28: Mo1 T7. A typical Chinchorro burial. Photo by Vivien Standen

In general, the bodies were wrapped up in reed mats made from different species of vegetable fibres; at other times they were covered with camelid skins. Although, in general, the bodies were interred naked underneath these mats, a few individuals were found buried wearing skirts (Fig 23), pubic coverings or loin cloths made of vegetable fibre or camelid wool. At other times they were covered externally by pelican skins with the feathers facing downwards sometimes painted in red ochre, or by knitted fabrics and blankets made of camelid wool. A few individuals had their body painted with ochre, green or blue pigments, particularly the face, trunk and arms (Focacci and Chacón, 1989).

Two types of mummies are commonly found in a Chinchorro cemetery, natural mummies and artificial mummies. The latter group represent the oldest known in the world (Arriaza, 1995a) and include four variants, the black, the red, the bandaged and the mud-coated mummies (Arriaza, 1994; Standen, 2003). Artificial mummies, as their name suggests, were bodies treated internally (both eviscerating most of the soft tissues and reconstructing the body with wooden sticks, grass, ashes, animal and human hair or a combination of these materials) and externally (painting the body and face with a coating of pigments). Both males and females of all ages as well as children are represented by these variants (Aufderheide, 2003). Natural mummies resulted from spontaneous soft tissue preservation and rapid evaporation of body fluids secondary to the arid conditions of the Atacama Desert (Arriaza, 1994, 1995a; Aufderheide, 2003). These types of mummies date to the beginning and the end of the Chinchorro culture, around 7,000 and 2,000 BC (Arriaza, 1994). Artificially mummified bodies were, on the other hand, present between ca. 6,000 and 2,000 BC. The reasons behind the diachronic changes in mummification styles have not been studied in depth, however, Arriaza (1994, 1995a) suggested that these could have resulted from social changes occurring within the Chinchorro society over time.

In most Chinchorro cemeteries, bodies were aligned in groups according to their mummification styles, in other cases, intermingled bodies belonging to different mummification styles appeared buried together in a cemetery. Standen (1997) studied the spatial distribution of individuals buried at the cemetery of Morro 1 and the types of mummification technique applied to them. The author distinguished four clusters of mummies buried together in which two groups presented a similar mummification treatment (group 1 were all black mummies and group 2 were all red mummies). The remaining two other groups included a variety of mummification techniques (group 3 were red and bandaged mummies and group 4 were red and mud-coated mummies) with no evident differentiation according to age or sex. Despite the difficulty in trying to evaluate the time between inhumations, Standen (1997) suggested that there is a tendency for contemporaneity as the mummies in each group were buried next to one another and sometimes at the same stratigraphic level. This observation led the author to hypothesise two ideas. Firstly, that bodies aligned in these groups could be interpreted as nuclear families, however, the author later concluded that the spatial distribution of individuals buried at cemetery Morro 1 was identical to that of other Chinchorro cemeteries where no logical or apparent distribution of buried families could be interpreted. Secondly, Standen (1991, 1997) also suggested that mortuary treatment among Chinchorro people was selective. The author based this assumption on the basis that not everyone in cemetery Morro 1 was artificially mummified and that bodies with different types of mummification techniques were found buried together. For instance, neonates and infants of all ages were always artificially mummified regardless of their location in the cemetery or time. Although the reasons behind this special treatment have not been thoroughly addressed, Standen (1997) suggested that the fact that neonates and infants received a "privileged" burial demonstrates the existence of complex selective mechanisms operating within this society and also, in the view of Aufderheide (2003), their profound spiritual beliefs and deep emotions towards their dead.

In opposition to this opinion, Focacci and Chacón (1989) and Arriaza (1994, 1995a) argued that the presence of the purported synchronic-hierarchical differentiation among this group can be explained by the intermingling of different types of mummies, which would indicate the reuse of the funerary space over time.
The distribution of naturally and man-made mummies within Chinchorro cemeteries, along with the presumed underlying social inequalities is far from completely understood. A more recent study conducted by Arriaza *et al.* (2005) looked at a cluster of 15 radio-carbon dated Chinchorro mummies buried together with different mummification practices. This showed that the evolutionary style classification is valid but that naturally mummified individuals were present during the black and red mummy's era, thus reinforcing the idea that artificial mummification was applied selectively in each period. Despite the low number of individuals chosen for analysis, one question that remains unanswered is, if the practice of artificial mummification,

which is seen as a highly energy-demanding practice, was only applied to high status members, it would not be expected to occur so frequently. According to Arriaza *et al*. (2005) 63% of the bodies were artificially mummified compared with 37% of naturally mummified remains at cemetery Morro 1.

In an attempt to clarify the presence of different types of mummies and the possible link with hierarchy and social status, Standen (2003) analysed the grave goods found in the cemetery Morro 1. Grave goods usually consisted of artefacts reflecting fishing and hunting. They were found between the reed mat layers or placed on top of the body (Aufderheide, 2003). Such elements were harpoons, throwing sticks and atlatls, cactus needles and fishhooks, or small mesh net bags to transport collected fish. Personal ornaments and decoration items included necklaces made of shell beads and lithic artefacts (Focacci and Chacón, 1989). Standen (2003) observed that on the basis of grave good analysis, Chinchorro males and females played different roles in society. Women were associated with fishing tools used to catch small fishes (fishhooks, fishing weights and fishing lines), while men were associated with tools for hunting larger sea mammals (arrow shafts and harpoon barbs). Harpoon heads on the other hand, did not show any particular trend as they were found associated with individuals from both sexes and all ages (Standen, 2003).

In summary, a number of conclusions can be drawn from the analysis of the mummification techniques practised by the Chinchorro people and their grave goods. Despite the fact that grave goods accompanied the dead, none of the items suggested differential social status or were identifiable as belonging to elite individuals. This would suggest that there was no social stratification among the Chinchorros as observed in later agricultural societies of the region according to Arriaza (1995a, b). It appears that no individual accumulated any great wealth, prestige or social rank since grave goods were not concentrated with any particular individual. The lack of evidence of tombs or similar functional structure in their cemeteries would also support this idea (Arriaza, 1995b; Auderheide, 2003). On the other hand, questions remain regarding the presence of more than one type of different styles of mummies coexisting in Chinchorro cemeteries and whether this results from social differentiation or circumstantial treatment of the dead (Arriaza *et al*., 2004).

3.2.3 Previous work conducted on the samples

The coastal fishers have been intensively studied by a number of local and international researchers. Numerous archaeological and bioarchaeological studies conducted on these populations has resulted in a number of scientific publications, masters and doctoral theses as well as a number of books. Early studies on the coastal fishers focused attention on mummification techniques practised by these people (Allison *et al.*, 1984; Arriaza, 1994, 1995a and b). Two types of mummies were commonly found in a Chinchorro cemetery, natural mummies and artificial mummies. The former group was present towards the beginning and the end of the Chinchorro culture, around BC 7,000 and 2,000 (Arriaza, 1994). Artificially mummified bodies were present between ca. BC 6,000 and 2,000 and as discussed above these were bodies treated externally and internally and include four variants, the black, the red, the bandage and the mud-coated mummies. Both males and females of all ages as well as children are represented by these variants (Aufderheide, 2003).

A variety of bioarchaeological studies have been conducted on these samples, including: the influence of cranial deformation on facial morphology (Rhode and Arriaza, 2006), the evidence of systemic stress including Harris lines (Arriaza *et al*., 1984a), porotic hyperostosis (Focacci and Chacón, 1989) dental attrition (Langsjoen, 1996) and dental enamel hipoplasia (Alfonso *et al*., 2007). Other health-related studies are those of Allison and Gertszten (1982) and Standen *et al*. (1984). The former authors revealed that the major cause of death among Chinchorro children and also among adult individuals was pulmonary disease, commonly pneumonia. Standen *et al*. (1984) focused her attention on a number of pathological conditions present in the population buried at the cemetery of Morro 1. For instance, certain metabolic disturbances such as osteoporosis were evident in the spine of six out of a sample of 45 (13%) spines available. A possible case of nasopharyngeal neoplasm in the form of carcinoma or chondroma and three possible cases of treponematosis (sabre tibiae and periostitis in long bones) were identified in 96 Chinchorro skeletons analysed. Genetic anomalies tended to occur more frequently in the vertebral column of these populations with a number of variations present on the spinous and transverse processes. According to Standen *et al*. (1984) there is a lack of detailed studies addressing pathological aspects of these populations and although their study should not be taken conclusively as it was based on only a small number of Chinchorro individuals, it represents the first attempt to reconstruct bioarchaeological aspects of their health and disease. Studies on trauma and interpersonal violence were also addressed in Standen *et al*. (1984) and later in Standen and Arriaza (2000a). Finally, the evidence for certain inflammatory diseases affecting the entheses and joints revealed that seronegative spondyloarthropathies (SNS) and diffuse idiopathic skeletal hyperostosis (DISH) were present among these coastal populations with prevalences of 5.6% (4/72) and 4.8% (1/21) respectively (Arriaza, 1993).

Examples of physical activities and occupation among these populations are of particular importance given the objectives and aims of this study. Previous studies on activity-related skeletal changes among coastal Chinchorros have focused on the presence of external auditory exostosis, spondylolysis and osteoarthritis. External auditory exostosis has been consistently found affecting the ear canals of Chinchorro men (36%, 9/25) more than the females (4%, 1/23) (Standen *et al*., 1984, 1985, 1995). As this condition is believed to result from repeated immersion in cold waters as a probable consequence of diving and swimming to fish and gather seafood, the authors suggested a possible link between the condition and sexual division of labour.

The presence of spondylolysis among the Chinchorro people has shown according to Arriaza (1995a, 2003) that only men were affected by this condition (18%, 5/28 in males compared with 0%, 0/23 in females). As reviewed in section 2.3.6 of Chapter two, the author attributed the presence of this condition to the physically demanding tasks practised by Chinchorro men, probably resulting from hyperextension of the back when throwing harpoons and atlatls, or from falling on the rocky areas in the coastal Pacific environment that they lived in.

With regards to osteoarthritis, the condition has not been systematically analysed. The vertebral column has been the main area of study. Other extraspinal locations including the knee and ankle joints were also analysed, although this was based on only four individuals (Standen *et al*., 1984). The authors reported that vertebral osteophytosis was more prevalent among the Chinchorro females (47%, 9/19) compared with the males (33%, 5/15). The former group was affected in the cervical and lumbar areas, whereas the males were more affected on the thoracic and lumbar areas.

Other relevant studies include those within the field of palaeoparasitological, such as that of Guhl *et al.* (1999) and Arriaza *et al.* (1998) which have shown how the presence of soft tissues in human remains is valuable in performing biomolecular analysis. The former authors reported the first case of DNA isolation of *Trypanosoma cruzi* in a 4,000 year old Chinchorro mummy. This parasite is known to produce Chagas's disease, the most prevalent vector-borne disease in Latin America. A more recent paper (Aufderheide *et al*., 2004) also reported the presence of this parasite in a much larger sample spanning temporally over 9,000 years of prehistory in northern Chile. Other parasites such as the marine tapeworm or *Diphyllobothrium pacificum* found in human coprolites were also found affecting these populations (Arriaza, 1995a; Arriaza *et al*., 1998; Reinhard and Urban, 2003). Ectoparasites such as *Pediculus humanus* commonly known as "lice" have also been found in the hair of these mummies (Aufderheide and Rodríguez-Martín, 1998). Other biomolecular studies using hair of Chinchorro people revealed high levels of arsenic consumption. This mineral is still found today in the north of Chile at levels up to 100 times the recommended limit. It is known to cause a number of ailments including premature birth, stillbirths, neonatal disorders, skin problems and various types of cancer (Arriaza *et al*., 2010). Finally, studies of pre-Columbian tuberculosis failed to demonstrate the presence of *Mycobacterium tuberculosis* among the coastal Chinchorros. However, the condition was confirmed in an individual belonging to later inland agriculturalists (Arriaza *et al*., 1995).

3.2.4 Sample composition

The sample of coastal fishers was comprised of approximately 220 individuals of all ages and sexes buried at four cemetery sites, Morro 1 (Mo1), Morro 1/6 (Mo1/6), Morro 1/5 (Mo1/5) and Quiani 7 (Qui7). From these, 75 adults were in good condition to be used for the present study. The remainder were preserved with too much soft tissue to allow the observation of potential markers of occupational stress present in the skeleton. The final population structure is presented in Table 24 of Chapter five.

Detailed information for each cemetery was not always available. Some of them have been intensively studied, resulting in a number of comprehensive reports, publications, and doctoral theses. Some others have been poorly studied and little written information has been produced, particularly when the excavations resulted from rescue archaeology because of the danger of looting, or because building construction was taking place at the site.

(a) Cemetery of Morro 1

The cemetery of Morro 1 (Mo1) (Fig 29) was the most intensively studied cemetery belonging to the Chinchorro people. It was located on the southern slope of a hilly terrace locally known as the "Morro of Arica" near today's urban area of Arica city (Fig 19). It was excavated by Dr. Allison and co-workers during four months between 1983 and 1984 as a result of a rescue archaeological project (Allison *et al*., 1984).

Initial findings suggested that some bodies were found buried individually and others collectively including non-deliberate grouping (Fig 28), the latter resulting from superimposition and truncation due to the re-use of the funerary space (Standen, 1991). As a result of the excavation, nearly 134 bodies of all ages and of various degrees of preservation were unearthed. While some bodies had to be left buried in situ as the removal of sandy material on the slope represented a danger to the houses located nearby (Allison *et al*., 1984; Standen, 1991), the remaining available bodies were taken for further laboratory analysis. Of the total of 134 adult individuals excavated, only 39 skeletons were available for this study. This reduction in number was due to several reasons. A large number of them were incomplete bodies represented only by a few bony remains. On the other hand, the best preserved examples were taken for display to the Museo Arqueológico San Miguel de Azapa hence reducing the number of individuals available for analysis. Secondly, some mummies were kept as such with their soft tissues as originally found and those that were skeletonised sometimes exhibited too much soft tissue to be able to observe the MOS. Thirdly, for the purpose of this study, sub-adults individuals had to be taken out of the sample, which reduced the sample further.

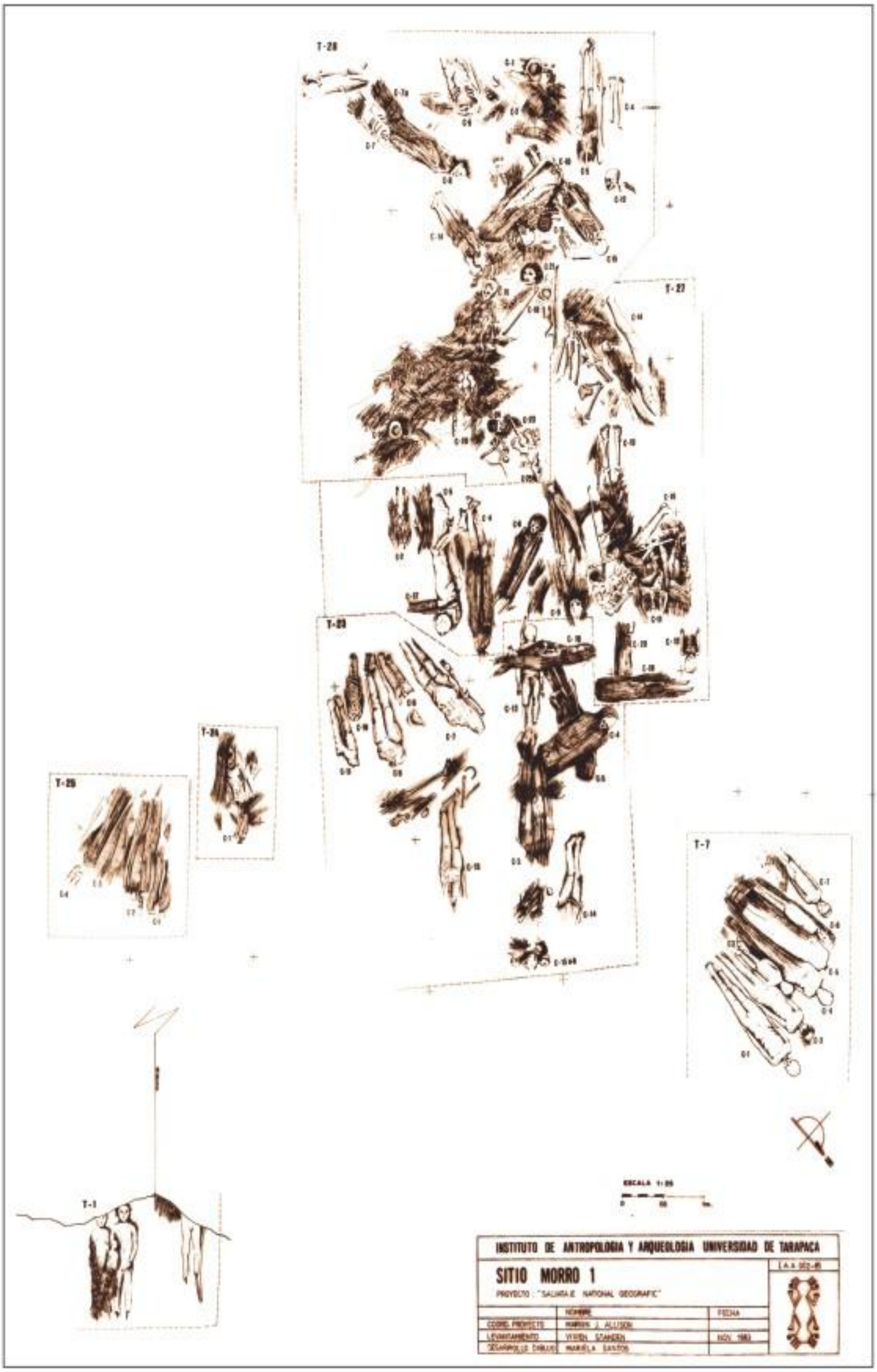


Figure 29: Cemetery of Morro 1
Archives of Museo Arqueológico San Miguel de Azapa

Of the 39 skeletons available for study, 19 were females (nine young adults, eight middle adults and two old adults) and 20 males (13 young adults, seven middle adults and no old adults). The final structure of the Chinchorro population is presented in Table 24 of Chapter five.

With regards to the chronology of Morro 1, Standen (2003) suggested that the cemetery showed an occupancy period of approximately 1,700 years spanning temporally over the Mid-Chinchorro period (Table 8). To understand the process of occupation of the cemetery, three phases were established according to radio-carbon dates, the mortuary pattern and the mummification techniques. The first period lasted from ca. BP 5,500 to 5,000, the second from ca. BP 4,600 to 4,000 BP and the third from ca. BP 4,000-3,600.

(b) Cemetery of Morro 1/6

The cemetery of Morro 1/6 (Mo1/6) (Fig 30) was located 30 metres east of Morro 1 (Fig 19). The first news about the site came to light in 1987 after two bodies were accidentally discovered by local builders who were levelling the ground while constructing a sports pitch. Following this, two test excavations were performed under the direction of Guillermo Focacci and Sergio Chacón to evaluate the significance of the sample. Initial excavation showed that most bodies were buried only 20 or 30cm below the ground and therefore severely affected by wind erosion. However, the bodies found buried deeper in the sand were preserved in an excellent condition. A total of 62 bodies were recovered from this cemetery, 27 resulted from the first excavation (Fig 31) and another 35 bodies were found 100 metres east from the preceding excavation (Fig 32).

The population of Morro 1/6 was largely comprised of adults and adolescents and to lesser extent newborn infants, whose fragile bones were destroyed by the removal of the sand. From the 62 naturally mummified remains excavated from this cemetery, 31 were available for this study, 16 females (10 young adults, 4 middle adults and two old adults) and 15 males (six young adults, six middle adults and three old adults. The remaining 31 mummies out of the 62 recovered were unavailable for study. Of these 23 of them were sub-adult individuals. The other eight remaining exhibited too much soft tissue that prevented the observation of the MOS. The final structure of the coastal fisher's population is presented in Table 24 of Chapter five.

Figure 30: View of the cemetery of Morro 1/6. Note the depression in the dune that resulted from the excavation. Photo taken form "El Morro of Arica", the city centre of Arica and the Pacific coast at the far. Photo by Paola Ponce

In line with typical Chinchorro funerary practice, the majority of the bodies were buried in an extended position with the arms to the sides, with six out of 62 individuals laid on one side and two with the legs semi-flexed. They were buried directly into the sand without coffins in collective burials sometimes very close to one another, with a few individuals intercutting other graves. The reason why the funerary bundles showed post-mortem disturbance was, according to Focacci and Chacón (1989), due to the re use of the burial space over time.

Each body was covered externally in reed nets made from various species of vegetable fibres. Although in general terms, the bodies were interred naked underneath these mats, a few individuals were buried wearing a *faldellín*, a small cord-made skirt suspended from the waist (Fig 23), a pubic cover or a loin cloth made of vegetable fibre or camelid wool. Other times they were covered by pelican skins, with feathers facing inwards sometimes painted in red ochre, or by knitted fabrics and blankets made of camelid wool. A few individuals had their body painted with green or blue ochre, particularly the face, trunk and arms (Focacci and Chacón, 1989).

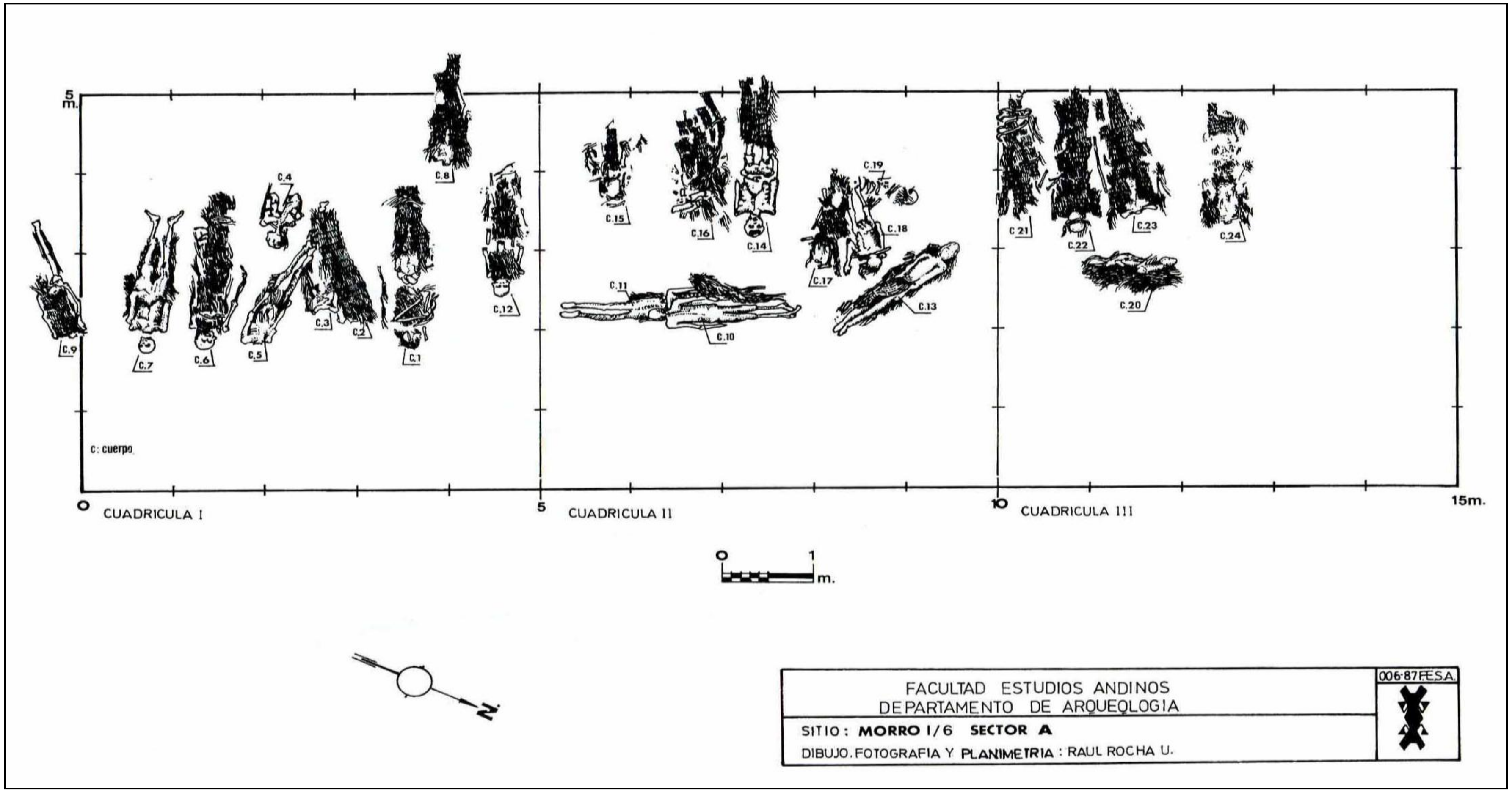


Figure 31: Map of cemetery Morro 1/6. First excavation (sector A). From Focacci and Chacón (1989)

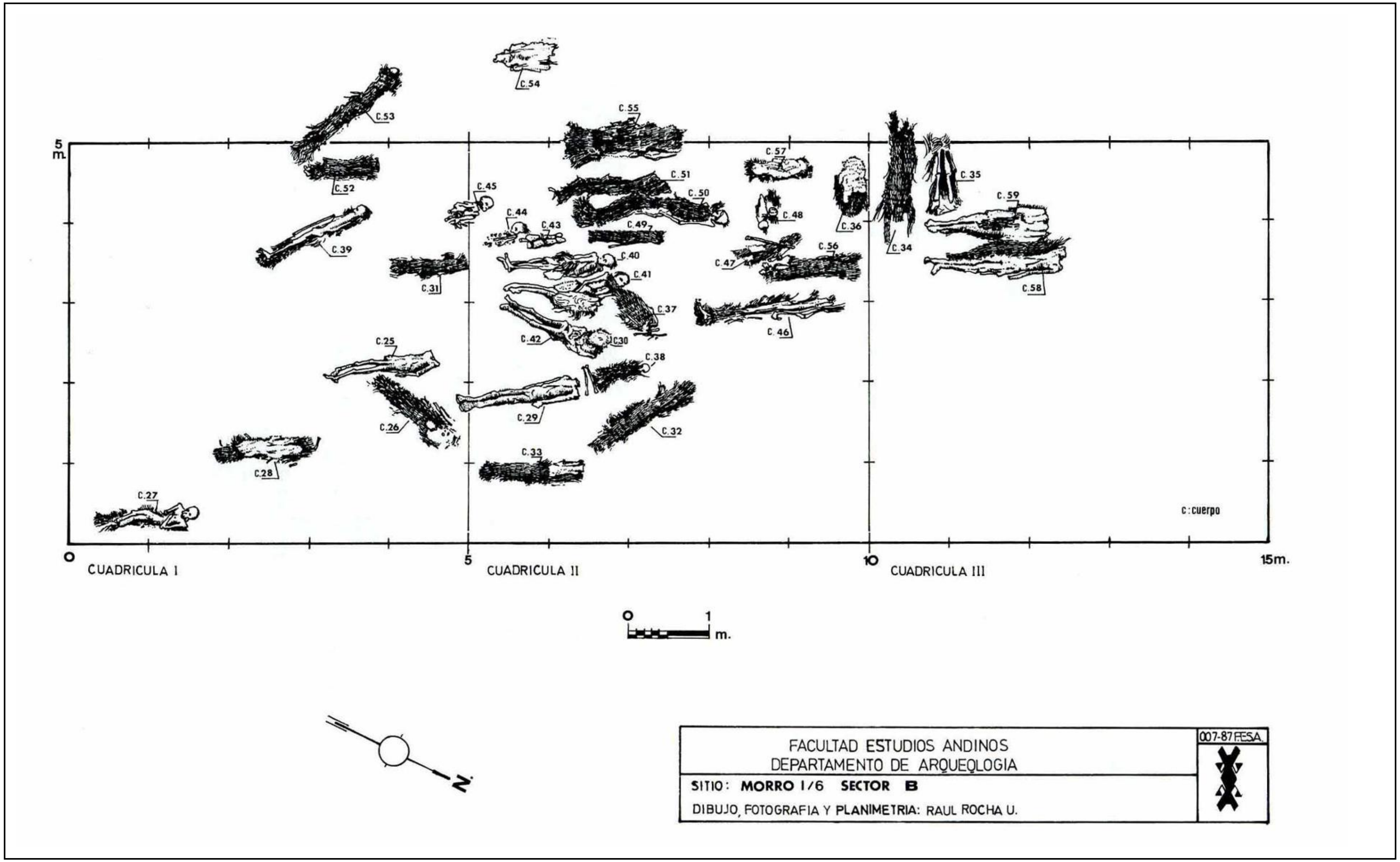


Figure 32: Map of cemetery Morro 1/6. Second excavation (sector B). From Focacci and Chacón (1989)

Grave goods, usually consisted of fishing and hunting gear artefacts. They were found within the woven split reed wrapping or placed on top of the body. They consisted of harpoon foreshafts, cactus needles and fishhooks or small mesh net bags to transport collected fish. Personal ornaments and decoration items included necklaces made of shell beads and lythics (Focacci and Chacón, 1989).

Finally, with regards to the chronology of Morro 1/6, a number of radiocarbon dates were obtained from muscle tissue of mummies buried in this cemetery (Focacci and Chacón, 1989). These suggested that the cemetery belonged to the Mid-Chinchorro period and continued into the Late-Chinchorro period spanning approximately between BP 4,000 and 3,500 years (Table 8).

(c) Cemetery of Morro 1/5

Under similar circumstances, the cemetery of Morro 1/5 (Mo1/5) was located in the vicinity of other Chinchorro sites (Fig 19) and was excavated by the archaeologist Guillermo Focacci in 1985 as a salvage project. Although he did not publish the original findings, he produced a number of written materials such as personal records and fieldwork documents that have been extremely useful for the comprehension of this cemetery. A total of 17 individuals were rescued by Focacci, all of them shallowly buried without any evident orientation pattern and in complete disarray. It is not clear whether the bodies were all interred at the same time or within a short period of time. Except for one adult individual, the other 16 were artificially mummified bodies; 14 were sub-adults and two were adults (Guillén, 1987, 1992). From the total of 17 mummies excavated from this cemetery, only three individuals were available for this study, two males (one young adult and one middle adult) and one middle adult female. The remaining 14 mummies were sub-adult individuals and hence were excluded from the sample. The final structure of the Chinchorro population is presented in Table 24 of Chapter five.

With regards to the chronology of Morro 1/5, a radiocarbon dating analysis was performed on liver tissue on one mummy buried in this cemetery which suggested that these burials belonged to the mid-late Chinchorro period, BP 4,120 ± 75 (Guillén, 1992).

(d) Cemetery of Quiani 7

Finally, the cemetery of Quiani 7 (Qui7) was another archaic cemetery of fishers located 1.5-2km from the above mentioned Chinchorro cemeteries (Fig 19). Dauelsberg (1974) unearthed seven naturally mummified bodies of adult individuals belonging to various age groups and with different degrees of preservation. Two individuals out of the seven recovered from this site were available for this study; these were a middle adult female and a middle adult male. The remaining five mummies exhibited too much soft tissue that prevented the observation of the MOS. The final structure of the coastal Chinchorro population is presented in Table 24 of Chapter five.
The mummies buried at Quiani 7 were located in a natural sandy cave, 20 metres above sea level, and despite having been disturbed by heavy machinery involved with roadworks, valuable information regarding their mortuary patterns was still possible to obtain. Contrary to previous Chinchorro funerary patterns, individuals buried at Quiani 7 were placed with their arms and legs in a flexed position lying on one side in a circular burial pit (Dauelsberg, 1974). Grouped burials were no longer the focus of attention in this cemetery as individuals appeared now buried in separate bundles. Each funerary bundle was generally covered with reed mats and baskets of different types and sizes accompanied by their grave goods, which in line with the above description, consisted of marine fishing and hunting items. In addition to wooden and bone harpoon heads, harpoon shafts, lithic points, cactus and shell fishhooks, Quiani 7 individuals were buried with baskets made of vegetable fibres (Dauelsberg, 1974). This innovation along with the presence of elaborate hair braiding and yarns wrapping the head of individuals resembling turbans also appeared during this period. Other important socioeconomic developments included the evidence of early horticulture as tubers and cucurbits appeared for the first time as part of the grave good (Dauelsberg, 1974; Arriaza, 1995a).

In summary, on the basis of the practice of agricultural experimentation, basketry and the differences in mortuary patterns found between these individuals and those belonging to Morro 1, 1/5 and 1/6, Arriaza (1995a) suggested that Quiani 7 was a post-Chinchorro site. Hence, they probably represented the descendants of the Chinchorro people or a transitional group between their marine-hunting predecessors and the subsequent agriculturalists.

With regards to the chronology of Quiani 7, a number of radiocarbon dating analysis based on soft tissues extracted from these mummies suggested that the cemetery dated between ca. BC 1,640 to 1,300 (Arriaza, 1995a).

Finally, with the exception of cemetery Quiani 7, which was located relatively distant from those buried in the vicinity of Arica city centre, Standen (2003) proposed that because of the funerary patterns, cultural context, geographical location and radio carbon dates, Morro 1, Morro 1/6 and Morro 1/5 all belonged to a single cemetery population stratum.

3.3 The inland agriculturalists

The inland agricultural group was comprised of individuals recovered from the cemeteries of Azapa71 (Az71), Azapa140 (Az140) and Azapa141 (Az141) (Fig 19). As with the coastal fishers, numerous radio-carbon dating analysis has been derived from the mummies from these cemeteries, particularly from muscle tissue. The skeletons of these inland agriculturalists date to the 1st millennium AD (Santoro, 1980; Focacci, 1981; Muñoz, 1981, 1983, 2004). The individuals buried at these cemeteries belonged to three cultural groups, the “Cabuza”, “Maitas Chiribaya” and “San Miguel” spanning the 1st millennium AD three cultural periods (Table 8). For the remainder of this study the name “inland agriculturalists” will be used here to refer to these groups on the basis of the subsistence economy they practised, which was mainly based on intensive agriculture.

The inland agriculturalists were sedentary populations, who settled in large villages where domestic, funerary, administrative and defensive structures were spatially connected. These were located along the lower slopes of the middle course of the Azapa Valley in northern Chile, between 15 and 25 km from the coast and the city of

Arica, at 200-250 metres above sea level. The Atacama Desert is in this territory characterised as a narrow and enclosed landscape with steep slopes and deep canyons, which appear to make human occupation difficult. Inland agriculturalists adapted to this environment by developing intensive agriculture, farming, and herding. The arrival of agriculture and the consequent sedentarism and further social changes was possible thanks to a number of favourable geographical and environmental conditions that are worth highlighting.

Firstly, the river San José, whose source is in the high Andean cordillera and flows into the Pacific Ocean, circulates along the Azapa valley and provided an invaluable resource for humans to practise agriculture without the necessity of irrigation. Although during the middle and lower regions of the valley the river course flows underground, it frequently emerges superficially through springs and swamps. Along with this, and despite the absence of annual precipitation, the abundant mist and fog that the valley receives throughout the year are key features that favour the growth of wild flora. Different species of rodents and birds such as guinea pigs, flamingos, herons and ducks, as well as llamas and guanacos, would have been attracted to the area by the freshwater resource and the vegetation such as green grass, reed mace, bitter willows, cotton, pepper, and cane, as well as other wild plants (Muñoz, 2004).

Secondly, agriculture within this area was possible not only because of the valuable resources offered by the valley such as freshwater, animals to hunt and wild vegetation for consumption or for other utility purposes, but also because of its proximity to the coast and its connection to the highlands. The relatively easy access to marine and highland resources would have allowed the inland agriculturalists to invest more time in agricultural tasks in the valley (Muñoz, 2004). Within a short distance of the village and available throughout the year, marine resources provided an important dietary supplement, particularly when the agriculture was affected by environmental changes such as those produced by the El Niño current (the periodic climate pattern that occurs across the Pacific Ocean). Similarly, the connection with the highlands of the Andes and its populations provided an important trading system for highland products such as coca leaves, potatoes and maize, and the possibility to establish vital social networks with other populations (Muñoz, 1986, 2004).

Thirdly, the valley was probably chosen for cultivation because the soil has good natural drainage and is relatively rich in nutrients. The river plain extended between 800 and 1,000 metres across the valley providing a relatively flat fertile area for irrigation and cultivation.

In summary, according to Muñoz (2004), the agricultural process was possible in the arid valley of Azapa thanks to a combination of geographical, environmental and ecological factors. All of these permitted the settlement of these populations and gave them an alternative to hunting and gathering food practised by earlier inland populations.

In line with the agricultural way of life in settled villages, a number of other important social and economic events developed during the presence of inland agriculturalists in these areas. These include the development of a sophisticated textile and ceramic industry and the practise of smelting metals.

Sexual division of labour, resulting from the emergence of professionals and specialists governed by a chief or an elite group of chiefs, would suggest a complex internal social organisation (Muñoz, 1983; Rivera, 1988; Alfonso *et al.*, 2007). The presence of a select group of male individuals, the so-called “orejones” (big eared men) due to their pierced ear lobes and earrings made of pieces of wrapped camelid fur or corn cobs, beautifully decorated with silver and gold plates at one end, might suggest the presence of individuals of a special class (Allison *et al*., 1983). Individuals found with hair decoration in the form of headdress arrangements with gold as well as wearing “hats of four points” (Fig 39) would also give support to this idea (Muñoz, 1981, 2004).

Finally, one important social and symbolic element adopted by inland agriculturalists was the consumption of psychoactive plants. As observed in funerary contexts, particularly among grave goods, the presence of a number of items linked to drug consumption and hallucinogenic practices such as snuffing tablets and tubes and brushes of vegetal fibres would emphasise the important role this practice played in the ritual lives of these people (Santoro, 1980; Berenguer, 1985; Ogalde *et al*., 2009).

3.3.1 Subsistence economy, diet and lifestyle

As highlighted above, the main subsistence economy of inland agriculturalists of course was agriculture. The evidence to support this premise comes from analysis of vegetables and seeds (Fig 33) found within domestic and funerary contexts as well as that provided by middens and coprolites (Muñoz, 1981, 1983, 2004).

Inland agriculturalists cultivated different varieties of maize and tubers such as yucca, tapioca, potato and sweet potato. They also grew different types of cucurbits including pumpkins and butternut squashes, chillies, peanuts, quinoa, cotton, coca and different types of beans (Focacci, 1981; Muñoz, 1983; Alfonso *et al.*, 2007). Besides consumption, cucurbits were also used for domestic purposes as spoons and food containers (Fig 34).

Figure 33: Different types of seeds. Elements from Museo Arqueológico San Miguel de Azapa. Photo by Raúl Rocha

Figure 34: Different types of cucurbits. Artefacts from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

A number of structures such as silos or “colcas” found outside domestic areas would indicate that production was higher than consumption, therefore suggesting demographic stability and possibly trading or redistribution of the surplus (Muñoz, 1983; Rivera, 1988).

Further evidence of agricultural activity comes from a number of agricultural tools (Fig 35) found in domestic and funerary contexts including sharp wooden sticks, hoes, wooden shovels, and lithic axes that were probably used to plough the soil (Muñoz, 1983; Focacci, 1993). Tools for food processing such as pestles and mortars (Fig 36) were also found in a number of excavations.

Figure 35: Examples of agricultural tools. Artefacts from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

Figure 36: Examples of pestles and mortars. Artefacts from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

Inland agriculturalists complemented their diet with terrestrial hunting and gathering. The former activity included hunting birds and foxes with bows, arrows and darts (Focacci, 1981; Muñoz, 1981, 1983, 1986, 2004). It has been suggested that the presence of small structures in the form of corrals or pens, as well as geoglyphs in the slopes of the hills showing men herding camelids and the evidence of sacrificed llamas buried outside domestic areas, may indicate that they domesticated these animals.

Along with these, there are also archaeological indications of the domestication of guinea pigs and dogs (Focacci, 1981; Muñoz, 1983; Aufderheide, 2003).

Gathering involved the collection of wild plants such as rushes, totora reeds, rattan jonquil and other bushy species such as the carob tree. These were used as a raw material for funerary and domestic purposes. The preparation of tombs, including their internal layers and ceiling, as well as certain offerings, and the shroud that was used to wrap the dead, were all made with these plants. Other basic elements such as awnings and mats to cover their houses and huts, wooden logs to use as columns and support, were made from the wild vegetation that still grows today in the area (Muñoz, 1981, 1983, 2004).

Gathering marine products appears to have been complementary to the agricultural economy during the Middle and Late Intermediate period. A number of marine products (shells, bones and vertebrae of fish, seaweed and dried fish) as well as tools related to marine exploitation (fishing nets, cactus fishhooks, harpoons, lithic sinkers, and chopes or mollusc extractors, resembling those used by early coastal populations) were sometimes found in funerary contexts (Muñoz, 1981).

According to a study on external auditory exostosis, an activity-related condition believed to result from diving and swimming in cold waters (Standen *et al*., 1995), this condition was present in 2.3% (6/258) of inland agriculturalists compared with 30.7% (103/233) of coastal Chinchorros. This suggests that despite evident connections with the coast, gathering and fishing marine products were only a complementary activity for these populations. Contrary to this idea, Focacci (1993) suggested that these maritime products were probably obtained from trading rather than being exploited by these groups as there is no evidence of inland agriculturalists settling on the coast during these periods.

Other important activities performed by these inland agriculturalists were the practices of making pottery and textiles. These items are found in habitational and funerary contexts and tend to resemble those of the surrounding Titicaca and Tiahuanaco highlands societies (Muñoz, 1983; Focacci, 1993). A number of ceramic styles are recognised during the Middle and Late Intermediate period (Table 8) including those of the cultures studied here (Cabuza, Maytas, San Miguel). In general terms these styles can be characterised as usually red in colour and decorated in black with spiral and serpent like lines of globular shapes including mugs, cups and “keros” or glasses, jars, jugs or “pucos”, plates, pans, and bowls with a convex base and round handles. These elements were sometimes moulded adopting eagle-like zoomorphic forms (Focacci, 1981, 1993; Muñoz, 1983).

The textile industry peaked during the first millennium AD. This industry was based on the use of camelid wool as a raw material with the help of weaving looms and other weaving tools including spindles and whorls (Fig 37). Inland agriculturalists introduced a new concept in colour composition and iconography depicting geometric and anthropomorphic designs (Rivera, 1988). New techniques included “floating threads” where various square, rectangular and zigzag motifs were added on the base fabric as “floating” by means of a colour effect (Ulloa, 1982). This technique was introduced on numerous items of personal, domestic and funerary use including shirts or tunics (Fig 38), pubic coverings, belts, hats (Fig 39), as well as small tapestries, mats and ropes for different purposes. Different types of bags and handbags were also found in funerary contexts containing corncobs, seeds, coca leaves or working tools. All these textile items were often decorated in green, red, blue, black, yellow and beige, and sometimes framed with geometric and circum Titicaca and Tiahuanaco motifs (Focacci, 1981; Muñoz, 1981, 1983; Ulloa, 1982; Rivera, 1988; Focacci, 1993).

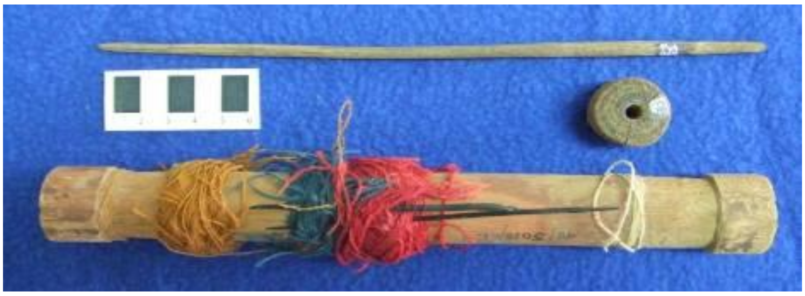


Figure 37: Knitting kit. Artefacts from Museo Arqueológico San Miguel de Azapa.
Photo by Paola Ponce

Figure 38: Decorated shirt with Tiahuanaco designs. Artefact from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

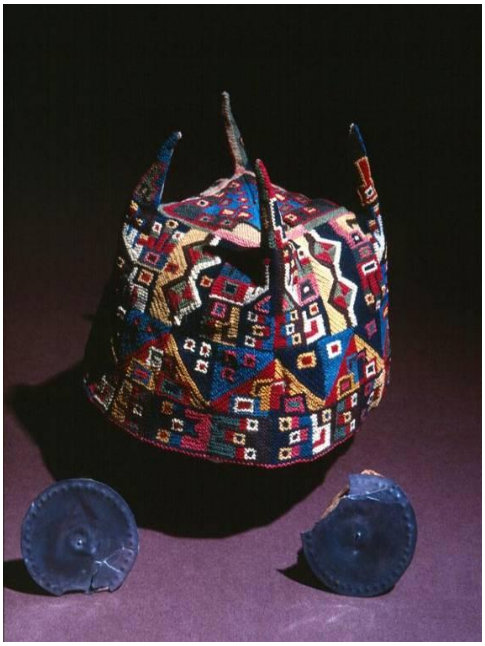


Figure 39: Hat of "four points" with geometric decoration. Photo by Raúl Rocha

The basketry industry was another popular and sophisticated activity among the inland agriculturalists. They manufactured domestic items resembling the forms observed in the pottery. These included plates and bowls of different sizes and shapes, containers, trays, and vessels and baskets, all made from thick spirals of totora and rattan jonquil sewn with fine threads (Fig 40). Similarly, various forms of mats were also made to wrap up the bodies of the deceased as well as awnings to cover their houses and huts (Muñoz, 1981, 1983, 2004).

Figure 40: Examples of domestic items made from vegetable fibres. Artefacts from Museo Arqueológico San Miguel de Azapa. Photo by Paola Ponce

Finally, another activity associated with the inland agriculturalists was the practice of smelting metals. This industry appeared towards the end of the archaeological presence of inland agriculturalists and flourished during the Inca period (Ponce, 2002). For this reason it has not been as intensively studied as other cultural legacies such as the textile, ceramic and basketry industries. On the other hand, a number of items of personal use such as different ornaments (bracelets, laminated or embossed pectorals, rings, and nose rings) and weapons (e.g. maces) were made of copper, silver or gold with different smelting techniques (Santoro, 1980; Castillo Narrea, 2008).

3.3.2 Funerary practice and grave goods

A typical inland agriculturalist burial consisted of a small singular underground tomb, circular or semicircular in shape of approximately 2 metres depth and with walls often covered internally with flat stones. Each individual was buried in a foetal or squatting position with their hands over their chest or abdomen. The bodies were dressed with a dark wool shirt tied up with a belt of vibrant colours. Their head and face were often covered with a handkerchief or "tari" and on their feet they wore flip flops made with the leather of llamas. Externally, the body was wrapped in a funerary bundle tied up with a string or rope made of camelid wool or totora reed (Fig 41) each individual was placed over a plaited reed mat with a selection of burial goods and other personal belongings (Focacci, 1981, 1993; Arriaza, 1995b; Muñoz, 2004).

Figure 41: Az140 T6 Typical funerary bundle of inland agriculturalists.
Photo by Paola Ponce

Finally, the tomb was filled with alternate layers of sediments, gravel and vegetable fibre giving a final appearance of an artificial burial mound or tumulus (Muñoz, 2004). Over the years, and with the unique climatic and environmental conditions of this region, the bodies followed natural desiccation and mummification.

Grave goods were placed on the floor of the grave, sometimes on the sides or on top of the head of the person. These items were described in section 3.3.1 of this chapter and identified as agricultural and marine products, decorated and non-decorated ceramic vessels, basketry items, artefacts made of wool, tools for farming, hunting and gathering marine resources, artefacts related to warfare including catapults, mazes and helmets and personal ornaments including necklaces made of shell, stones, bones, seeds and beads (Rivera, 1988; Focacci, 1993; Arriaza, 1995b; Muñoz, 2004; Aufderheide, 2003).

Unlike coastal fishers, the distribution of tombs in the cemeteries of the inland agriculturalists has not been studied extensively. The majority of the excavations of the cemeteries of these groups were conducted by Guillermo Focacci, Colagero Santoro and Iván Muñoz during the early 80's. They resulted from salvage archaeology due to the expansion for agricultural areas. As no maps were produced during the initial excavations, valuable information regarding mortuary practices in general have regretfully, been lost forever.

The analysis of the grave goods according to sex and age in order to interpret sexual division of labour, social status and stratification has likewise not yet been systematically conducted (Arriaza, 2009 pers. comm.; Muñoz, 2009 pers. comm.). As described in section 3.3 of this chapter, indirect evidence regarding social status and ranking has been identified among a select group of male individuals, the so-called "orejones" (big eared men). They had pierced ear lobes and beautifully decorated earrings that, according to Allison *et al*. (1983), might be suggestive of individuals of a special class. Similarly, individuals found with hair decoration in the form of headdress arrangements with gold, individuals buried with four-pointed hats or with psychoactive kits, would give support to this idea of a special class (Muñoz, 1981, 2004; Ogalde *et al*., 2009). Furthermore, on the basis of the textile evidence, Cassman (2000) analysed the overall style of shirts belonging to 436 mummies from the cemeteries of Azapa 71, Azapa 140 and Playa Miller 9. On the basis of surface embellishment, weave dyes as well as characteristics of yarns, the author concluded that social status differences was more in line with achieved status with some individuals having greater wealth accumulation as opposed to ascribed status or formalized rank differences.

Some information regarding funerary contexts during the Middle Period and Late Intermediate Period of Azapa (Table 8) was provided by Muñoz (2004). On the basis of the grave goods found in the cemeteries of Azapa 75 (Middle Period) the author observed that adults and non-adults did not show differences in tomb structure, position and orientation of the body although differences appeared in the grave goods. Children were buried with animals (dogs, baby llamas, guinea pigs) and sometimes they were found with necklaces, and ornaments made of vegetable fibre or copper, green copper ore, lapis lazuli, or sea shells decorating their ankles and wrists. Muñoz (2004) stated that adults were buried with working tools, pottery and basketry items but further information as to how these were divided according to sexes was not provided.

During the Late Intermediate Period, Muñoz (2004) observed that in the cemeteries of Azapa 76 and Azapa 22, in line with the previous period, there were no observable differences between the burials; although there were more distinct differences in the grave goods. Textile elements such as whorls and spindles, cactus needles, wool, and vichuñas (a tool made of camelid bone with a sharpened end used to thread and tighten the wool used in the weaving process) were all highly associated with females. Elements of maritime technology such as chopes and other mollusc's extractors, harpoons and fishing weights were associated with male burials, thus suggesting a possible sexual division of labour among these populations.

Despite admitting that differences in mortuary practices were absent among these populations, Muñoz (2004) described the exceptional examples of two burials of one adult male and one child in the cemetery of Azapa 76. These were unique due to the architectonic pattern of their graves and the quantity of grave goods. Elements of symbolic status found in the first of these tombs analysed included two wooden figurines representing individuals wearing a four-pointed hat, with a platted hairstyle and the ear lobes perforated. Along with these, a wooden glass or "kero" with a carved lizard-shaped handle, a comb with cactus teeth and a packet of arrows were also found among the grave goods. Finally, a second layer of grave goods contained three plates made of vegetable fibres embellished with geometric decorations, and another four more plates decorated in black depicting camelids, a bow without a string but with a preserved notch, three piriform-shaped butternut squashes and two small vessels decorated in black and white. The objects found in the grave belonging to the child consisted of a miniature ceramic “kero” glass, a vessel of globular shape, two sandals made in leather, a wooden spoon, a digging stick, a decorated basket and the remains of a small primate.

These observations, however as valuable as they are, were based on cemeteries not analysed in the present study. The lack of systematic studies on this material has prompted the need to carry out an analysis of the content of grave goods belonging to inland agriculturalists buried at the cemetery of Azapa 71, Azapa 140 and Azapa 141. Data on the grave goods was provided by the Department of Records, Museo Arqueológico San Miguel de Azapa along with the original fieldwork notes left by Guillermo Focacci, Colagero Santoro and Iván Muñoz and the initial laboratory reports left by Marvin Allison. As summarised in Table 24 of Chapter five, 100 skeletons from inland agriculturalists were used for this study. From this total, 78 were buried with a total of 619 items distributed as 256 with males and 342 with females. There was no information available for the remaining 22 individuals. From 619 grave goods, 60 were selected because they were considered according to Muñoz (1981, 2004), Ogalde *et al*. (2009) representative of physical activities and occupations practised by the sexes and also of social status and hierarchy. The list of these items is presented in Table 9.

In line with the descriptions provided by Muñoz (2004), items belonging to the textile industry such as balls of wool, needles, spindles and vichuñas were mostly associated with females. With a few exceptions, high status elements appeared to have been mostly associated with males. Agricultural tools for which descriptions of sex association has not yet been conducted, suggested that these were probably used mainly by females. Males on the other hand, were associated with food processing tools such as a mortar as well as warfare and metallurgy items. Hunting artefacts such as catapults, harpoon heads and arrow heads appeared to be associated with both sexes.

<table>
<tr><th colspan="2">Grave goods</th><th colspan="2">Females</th><th colspan="2">Males</th><th>Total</th></tr>
<tr><td rowspan="4">Textile industry</td><td>Needles</td><td>1</td><td>AZ140 T117</td><td>0</td><td></td><td>1</td></tr>
<tr><td>Spindles</td><td>2</td><td>AZ140 T117
AZ140 T100</td><td>0</td><td></td><td>2</td></tr>
<tr><td>Vichuñas
(thread tightener)</td><td>1</td><td>AZ140 T93</td><td>0</td><td></td><td>1</td></tr>
<tr><td>Ball of wool</td><td>11</td><td>AZ140 T27
AZ140 T126
AZ140 T116
AZ140 T110
AZ140 T100 (x2)
AZ140 T10
AZ140 TXPB
AZ71 TDD
AZ71 TBB
AZ71 E1</td><td>3</td><td>AZ140 T97
AZ140 T104
AZ140 T205</td><td>14</td></tr>
<tr><td rowspan="4">Hunting equipment</td><td>Harpoon heads</td><td>1</td><td>AZ71a T102</td><td>0</td><td></td><td>1</td></tr>
<tr><td>Arrow heads</td><td>1</td><td>AZ140 T124</td><td>0</td><td></td><td>1</td></tr>
<tr><td>Arrows</td><td>0</td><td></td><td>5</td><td>AZ141 T36
AZ141 T33 (x4)</td><td>5</td></tr>
<tr><td>Catapults</td><td>2</td><td>AZ140 T81
AZ140 T126</td><td>2</td><td>AZ140 T97
AZ140 T64A</td><td>4</td></tr>
<tr><td>Warfare</td><td>Mazes</td><td>0</td><td></td><td>1</td><td>AZ141 T52</td><td>1</td></tr>
<tr><td>Metal industry</td><td>Crucibles</td><td>0</td><td></td><td>1</td><td>AZ71 T245</td><td>1</td></tr>
<tr><td>Food processing</td><td>Mortars</td><td>0</td><td></td><td>1</td><td>AZ71 T606A</td><td>1</td></tr>
<tr><td>Agricultural tools</td><td>Digging sticks</td><td>3</td><td>AZ71 T615
AZ140 T8 (x2)</td><td>0</td><td></td><td>3</td></tr>
<tr><td rowspan="9">High status items</td><td>Kero (straw vessel)</td><td>0</td><td></td><td>2</td><td>AZ141 T53
Az71 T601</td><td>2</td></tr>
<tr><td>Kero (ceramic vessel)</td><td>1</td><td>AZ71a T84</td><td>3</td><td>AZ141 T52
AZ141 T46 (x2)</td><td>4</td></tr>
<tr><td>Earring</td><td>0</td><td></td><td>1</td><td>AZ140 T97</td><td>1</td></tr>
<tr><td>Four points hat</td><td>0</td><td></td><td>3</td><td>AZ141 T33 (x2)
AZ140 T122</td><td>3</td></tr>
<tr><td>Guinea pig remains</td><td>1</td><td>AZ140 T112</td><td>1</td><td>AZ140 T122</td><td>2</td></tr>
<tr><td>Sniffing tablet (hallucinogenic paraphernalia)</td><td>0</td><td></td><td>1</td><td>AZ141 T33</td><td>1</td></tr>
<tr><td>Spatula (hallucinogenic paraphernalia)</td><td>0</td><td></td><td>2</td><td>AZ141 T52
AZ141 T33</td><td>2</td></tr>
<tr><td>Camelid hoof</td><td>2</td><td>AZ71 T605 (x2)</td><td>3</td><td>AZ141 T36
AZ71 T601 (x2)</td><td>5</td></tr>
<tr><td>Zampoña (flute)</td><td>0</td><td></td><td>5</td><td>AZ141 T52
AZ141 T33 (x3)
AZ140 T122</td><td>5</td></tr>
<tr><td colspan="2">Total</td><td>26</td><td></td><td>34</td><td></td><td>60</td></tr>
</table>

Table 9: Grave goods recovered from the inland agriculturalists

3.3.3 Previous work conducted on the samples

As with the coastal fishers, inland agriculturalists have been previously studied from an archaeological and bioarchaeological perspective. These populations were examined for the presence of a number of pathological conditions including external auditory exostosis, treponematosis, seronegative spondyloarthropathies and DISH. However, in contrast to those studies of the coastal fishers, who did not develop a stratified society, a number of studies of the inland agriculturalists have attempted to address social aspects of their lifestyle. For instance, the so-called "orejones" or big ear men of Arica were investigated by Allison *et al.* (1983). These authors analysed the presence of this body adornment in individuals that belonged to the Cabuza, Maitas, San Miguel and Gentilar cultures (Table 8) spanning temporally from ca. AD 350- 1,300. These "orejones" were young adult and middle aged adult male individuals who according to Allison *et al.* (1983) were taller, healthier and had less pathologies than other non-orejones males, thus giving the impression they belonged to a privileged group. In relation to this study, Arriaza *et al*. (1986) analysed the hair styles present in northern Chile from the archaic period up to the arrival of the Incas in the region. They found that during the agricultural period of Arica, differences in hair styles could be attributed to social differentiation within the society as it was exemplified by a number of orejones and their particular hairstyles.

As suggested above, as with the studies of the Chinchorro people, inland agriculturalists have been the focus of biomolecular analysis. For instance, Fontana *et al.* (1983) sampled lung, kidney and heart tissue from 108 mummies belonging to five different time periods spanning from the Formative period to the Middle period (BC 800 to AD 1000) and found evidence of different strains of *Streptococcus sp* and *Salmonella sp*. The authors concluded that respiratory diseases were the main causes of death among these populations as 44% of individuals presented evidence of suffering from bacterial pulmonary diseases such as pneumonia and bronchopneumonia. Madden *et al*. (2001) used lung tissue from an individual buried at the cemetery of Azapa 141 dating to AD 1,000 from the Cabuza culture to test the presence of Chagas' disease. DNA isolation of *Trypanosoma cruzi* was found in the pulmonary tissue of this individual suggesting, as described earlier, that not only coastal Chinchorros (Guhl *et al.*, 1999) but also later agricultural populations were affected by this parasite (Aufderheide *et al*., 2004). Furthermore, unlike coastal Chinchorros, inland agriculturalists did not suffer from parasitic infestation such as *Diphyllobothrium pacificum.* According to Reinhard (1992) the shift to an agricultural subsistence where fish was replaced by tuber and fruits resulted in the decline of these marine tapeworms. Moreover, inland agriculturalists buried at the cemetery of Azapa 140 dating to the Late Intermediate Period (AD 1000–1400) (Table 8) have shown, in line with the results for the coastal Chinchorros, that the levels of arsenic consumption from the ground water were extremely high, as evidenced by the concentration levels in their hair (Arriaza *et al*., 2010). Finally, studies of pre-Columbian tuberculosis have shown that inland agriculturalists were affected by Pott's disease (Arriaza *et al.*, 1995). A segment of *Mycobacterium tuberculosis* DNA was identified in an 11-13 year old girl dating to AD 1.040 belonging to the Maitas Chiribaya culture (Table 8). However, the authors failed to demonstrate the presence of this condition among the coastal Chinchorros.

Biomolecular studies addressing social aspects of these populations, such as that of Cartmell *et al.* (1994), have shown that contrary to coastal fishers the practice of chewing coca leaves was present in inland agriculturalists. Radio-immunological analysis of human hair of these populations revealed that the custom appeared in the region approximately 2,000 years ago. Individuals from the Maitas-Chiribaya population including new born babies showed a high positive reaction to cocaine exposure, which in the case of the sub-adults may have been transferred both transplacentally and via breastfeeding from the mother. In line with this study, Ogalde *et al.* (2009) analysed the hair of 32 inland agriculturalists using gas chromatography-mass spectrometry. These mummies were buried at the cemeteries of Azapa 6, Azapa 70, Azapa 71, Azapa 140 and Azapa 141 spanning temporally ca AD 500-1,000. The consumption of psychoactive substances such as *Banisteriopsis* was confirmed in a small sample of individuals; thus suggesting that the presence of snuffing paraphernalia found in grave goods (highly decorated snuffing tablets and tubes) were not necessarily used for consumption of local psychoactive plants but *Banisteriopsis* that grows in the Amazonian rainforest. It was therefore suggested that extensive trading networks were present during the Tiwanaku empire connecting areas as far as the Atacama Desert and the Amazon.

Social aspects such as infant and maternal mortality among the inland populations were studied by Arriaza *et al.* (1984b, 1988). The authors observed that in the time period spanning 2,700 years from the Formative period (BC 1,000- AD 350) to the Late Intermediate period (AD 1,300-1450) (Table 8) infant mortality was high. Childbirth complications including puerperium and septic conditions as well as incomplete delivery and methods used that could have increased the risk of death accounted for 36.1% (155/429) of infant mortality and 13.4% (17/127) of maternal mortality (Arriaza *et al.*, 1984b). An evident decrease in infant and maternal mortality was observed during the late cultural phases of San Miguel (AD 1,200) and Gentilar (AD 1,200-1,400), which the authors associated with the application of new methods for delivery and prophylactic conditions although they did not reject the mere influence of the sample size (Arriaza *et al.*, 1988). In line with these studies, Alfonso *et al.* (2007) carried out an analysis of life expectancy among these populations comparing seven age categories. The authors found that life expectancy among Middle horizon individuals (AD 400-1,000) was slightly higher than that observed in earlier Formative inland populations (Table 8) but lower than that obtained for coastal Chinchorros.

Bioarchaeological studies of a different nature have been conducted on these samples with the aim of addressing the influence of cranial deformation on facial morphology (Rhode and Arriaza, 2006); the presence of pulmonary disease or pneumonia (Allison and Gerszten, 1982), the increase in incidence of seronegative spondyloarthropathies (SNS) and diffuse idiopathic skeletal hyperostosis (DISH) with the arrival of agriculture (Arriaza, 1993) and the presence of treponematosis (Standen and Arriaza, 2000b). Studies of dental disease among these populations revealed that the population of Maitas Chiribaya (AD 1,300-1,150) suffered considerably from antemortem molar tooth loss (Langsjoen, 1996). Comparisons between coca leaf chewers and non-chewers revealed that the former group was four times as likely to lose posterior teeth as the latter. Despite that Langsjoen (1996) did not reject the possible aetiological influence of a diet high in carbohydrate content that characterised these populations; the author suggested that the practice of coca leaf chewing could explain the excessive posterior edentulism of the Maitas Chiribaya. The positioning of the coca quid in direct contact with the mucosa of the cheek and the gingival mucosa of the posterior teeth corresponds to the pattern observed among these individuals. This assumption was supported by the near total absence of antemortem tooth loss among coastal Chinchorros and the absence of cocaine content in their hair follicles. In line with these results, Alfonso *et al*. (2007) observed that inland agriculturalists were more affected than Archaic Chinchorros not only by antemortem tooth loss but also dental enamel hypoplasia and caries. It was suggested that dental health in these Arica populations deteriorated with the arrival of agriculture as a consequence of the higher intake of carbohydrates and the changes in pattern of teeth wear resulting from softer cooked foods (and the introduction of cookware pottery).

Studies of physical activities and occupation among these populations are scarcer compared with that of the Chinchorro people, and sometimes the available information lacks any rigorous analysis. In other words, the information regarding the methods used to gather the data are not always provided and the statistical is absent. For instance, as discussed in Chapter two (section 2.2.6) Allison (1984) analysed the presence of cervical osteoarthritis in a group of individuals from the Maitas-Chiribaya culture dating to AD 1,000 and observed that male shamans exhibited the lowest prevalence of cervical and lumbar OA compared to the commoner males and females. The author attributed these social differences to the advent of agriculture that benefited a minority, the elite shamans, at the expense of the health of the bulk of the population.

The presence of external auditory exostosis revealed that, although in a comparatively low frequency, inland agriculturalists were like coastal Chinchorros affected by this condition (Standen *et al*., 1985; Standen *et al*., 1995; Standen *et al*., 1997). The authors therefore concluded that the exploitation of coastal resources by means of diving and swimming to fish and gather seafood was not exclusive to the Chinchorro people. In line with the funerary items found as grave goods in a number of burials from later agricultural populations (Focacci, 1993; Muñoz, 2004) the osteological evidence of this activity-related condition suggests that although agriculture dominated most of their subsistence economy, these groups did not abandon the maritime way of life as they complemented their terrestrial diet with marine produce (Standen *et al*., 1985). Standen *et al.* (1997) also hypothesised that gathering and fishing marine seafood was probably carried out not only for supplement and consumption but to produce a surplus to trade with other inland agricultural groups.

3.3.4 Sample composition

The sample of inland agriculturalists was comprised of approximately 600 individuals of all ages and sexes buried at three cemetery sites, Azapa71 (Az71), Azapa140 (Az140) and Azapa141 (Az141). From these, 100 adults were chosen to be used for the present study. Soft tissue preservation in these groups was substantially less then among the coastal Chinchorros, hence a larger number of inland agriculturalists were available for inclusion in the final population structure of this group. However, this would have led to an unbalanced number of individuals to compare with coastal fishers; therefore only 100 random skeletons were chosen.

As with the coastal fishers, detailed information for each cemetery was not always available. Some of them have been intensively studied, resulting in a number of comprehensive reports, publications, and doctoral theses. Some others have been poorly studied and little written information has been produced, particularly when the excavations resulted from rescue archaeology because of the danger presented by agricultural expansion in the Azapa valley. The final population structure of inland agriculturalists is presented in Table 24 of Chapter five.

(a) Cemetery of Azapa 71

The cemetery of Azapa 71 (Az71) (Fig 19) was located 15km from the coast on the north slope of a high terrace adjacent to the San Miguel river bank in the middle part of the Azapa valley (Santoro, 1980, 1981). It was excavated by Guillermo Focacci and Colagero Santoro in 1980 and the analysis of the skeletal remains was carried out by Dr Marvin Allison. According to Santoro (1981) approximately 398 graves with different degrees of preservation were uncovered from this cemetery. However, there were only 10 males and 21 females available for study without the presence soft tissue. The final population structure of this cemetery is presented in Table 24 of Chapter five.

These individuals spanned temporally and stratigraphically through three different time periods, the Formative period, the Middle period and the Late Intermediate period (BC 1, 000-AD 1,450) (Table 8). Individuals from three cultural groups were represented during these periods, the Cabuza, Maitas Chiribaya and the San Miguel (Table 8). According to Focacci (1981) the graves from the former group were located on the top of the slope following the second and finally the third group on the lowest parts of the hill.

The bodies buried at Azapa 71 were naturally mummified, sometimes painted in ochre and red, buried in a foetal or squatting position wrapped in a thin beige blanket made of camelid wool and a mat made of vegetable fibres (Focacci, 1981). Personal adornment and purported evidence of social status included a number of individuals wearing wrist and ankle bracelets made of wool and beads of bone and seeds, metal objects, and decorated textiles (Santoro, 1980).

The grave goods in this cemetery were abundant. Approximately 2,498 elements were recovered from the burial contexts which mostly consisted of basketry, textiles, pottery, food and vegetable fibre elements. They also included a number of basketry items decorated with geometric lines as well as vegetable offerings consisting of different types of beans and chillies. Cucurbits (pumpkin, butternut squash) were also present decorated and non-decorated sometimes containing flours or grinded vegetables. Vegetable fibre items included paintbrushes, mats, combs and ropes. Items of coastal and maritime origin were also found as part of the funerary paraphernalia, thus suggesting that these resources played an important part in complementing their existing agricultural diet. For instance, remains of fish, fishhooks made of cactus, fishing lines made of vegetable fibre, harpoons with detachable heads, knives made with shark teeth were also found in the burial bundle. Other offerings although less frequently found included a number of pottery items such as glasses and globular cooking pots. Absent from the grave good content were elements and produce resulting from terrestrial hunting (Santoro, 1980, 1981).

With regards to the chronology of this cemetery, Santoro (1980) reported five radiocarbon dates based on organic material found associated with the mummies of this cemetery. These included a wooden spoon, net mat, loin cloth, feathers, among many more and the results spanned from BP 2,855 ±85 to 2,560 ±85.

(b) Cemetery of Azapa 140

The cemetery of Azapa 140 (Az140) (Fig 19) was located on the south margin of a large sandy terrace near today's village of San Juan de Ocurica, in the Azapa valley (Fig 42). It was excavated by Guillermo Focacci and Ivan Muñoz in 1981. The former was responsible for excavating this cemetery and the latter the site of San Lorenzo, a contemporaneous habitation site located 500 mt from the cemetery of Azapa 140 and believed to have been closely associated with it (Muñoz, 1983). The main purpose of excavating the cemetery was to carry out research but also to prevent the damage caused by agricultural development in the area. A total of 147 individuals of various age groups representing the cultural periods of Maitas Chiribaya and San Miguel cultures (Table 8). These were distributed as follows: adults represented 60% (89/147) and sub-adults represented 40% (58/147). Of the 101 individuals whose sex was identified, 44% (44/101) were males and 56% (57/101) were females (Cassman, 1997). From these, 21 males and 37 females without preserved soft tissues were available for study. The final population structure of the inland agriculturalists is presented in Table 24 of Chapter five.

Figure 42: View of the cemetery Azapa 140. Photo by Paola Ponce

On the basis of the observation of the ceramic styles associated with the graves, Muñoz (1983) suggested that the older burials were found at the highest part of the slope and the later burials on the lower margins. The bodies were found dressed and wrapped in textiles with a selection of grave goods and placed in a foetal position within the burial pit. The same types of artefacts that were found in individual houses and middens were also found in the cemetery. These consisted of agricultural products, and agricultural tools as well as terrestrial hunting equipment and tools linked to the exploitation of marine resources. Different types of pottery, textiles, baskets as well as wind musical instruments such as whistles and reed flutes were also found in these contexts (Muñoz, 1983).

Once excavated, the bundles were taken to the Laboratory of Physical Anthropology at the Museo San Miguel de Azapa, in Arica, to be autopsied and radiographed by Dr. Marvin Allison. These mummies were later defleshed for standard skeletal analysis.

A number of studies have been carried out on the skeletal remains from this cemetery. Some of them have been described in section 3.3.3 and focused on pre-Columbian hair-styles (Arriaza *et al*., 1986), and pre-Columbian tuberculosis **(**Arriaza *et al*., 1995), ethnicity and status through the textile evidence (Cassman, 1997, 2000), earring styles (Allison *et al*., 1983), the presence of external auditory exostosis (Standen *et al*., 1995) among many more.

With regards to the chronology of Azapa 140, a number of radiocarbon dating analysis have been performed on muscle tissue mummies buried in this cemetery which have suggested that these burials spanned temporally through the Middle and Late Intermediate Period (AD 700-1,200) (Muñoz, 1983).

(c) Cemetery of Azapa 141

The cemetery of Azapa 141 (Az141) was the least studied cemetery from the three inland agriculturalist cemeteries. It was excavated by Guillermo Focacci during 1984 and the analysis of the skeletal remains was carried out by Dr Marvin Allison during 1985. No written report resulted from this excavation, therefore all the available information came from the fieldwork notes left by Focacci. Located approximately 22km from the coast and at the north margin of a high terrace adjacent to the river San José (Fig 19) this cemetery contained approximately 55 bodies of all ages, sexes and various degrees of preservation belonging to the Cabuza people (Table 8). From these 55 bodies found, 18 were males, ten were females, 14 were sub-adults and the reminder 13 individuals were incomplete, represented only by their crania. Available for this study without preserved soft tissues were seven males and four females. The final population structure of the inland agriculturalists is presented in Table 24 of Chapter five.

In line with the expected trend for this time period, the bodies from Azapa 141 were wrapped in blankets, and buried in circular and semicircular burial pits. A number of offerings were placed along with the bodies and these included as depicted earlier different types of agricultural products and tools, textiles of daily use, handbags, handkerchiefs, belts, as well as basketry and pottery items for domestic purposes including mugs, cups, plates, bowls, etc.

With regards to the chronology of Azapa 141, radiocarbon dating analysis has suggested that the cemetery occupancy spanned over the Middle period AD 900 to 1,300 according to the records held at the Laboratorio de Antropología Física, Museo Arqueológico San Miguel de Azapa in Arica.

3.4 Criteria for choosing the samples

To summarise, the coastal fishers were a group comprised of 75 individuals buried in four cemeteries: Morro 1 (Mo-1), Morro1-5 (Mo1-5), Morro 1-6 (Mo1-6) and Quiani 7 (Qui7). Only mummies dating from the 3rd -2nd millennium BC were used for this study. This was possible due to the numerous radiocarbon dating analyses performed on the mummies dug from these cemeteries, particularly from muscle tissue, bone and internal organs (liver), but also from elements found at the burial place including reed mat, wood and stuffing materials. Dating information on the chosen individuals was recovered from the records held at the Museo Arqueológico San Miguel de Azapa and also from a number of published papers including Focacci and Chacón (1989), Guillén

(1992), Aufderheide *et al.* (1993), Arriaza (1995a, 2003), Standen (2003). Inland agriculturalists on the other hand, comprised 100 individuals buried in three contemporary cemeteries Azapa 71 (Az71), Azapa 140 (Az140) and Azapa 141 (Az141). As with the coastal fishers, selected individuals spanning temporally over the 1st millennium AD were chosen for analysis. This selection was possible as each individual was curated with an identification card stating the cultural period they belonged to. Complementary information on the chronology of the samples and the radiocarbon dates derived from the mummies of these cemeteries has been described in a number of publications including Santoro (1980), Focacci (1981), Muñoz (1983, 2004), Madden *et al.* (2001).

The skeletal material used for this study was primarily chosen because, above all and during life, coastal fishers and inland agriculturalists practised different subsistence economies (Arriaza, 1995a; Aufderheide, 2003; Muñoz, 2004; Alfonso *et al*., 2007; Arriaza *et al.*, 2008) from which potential "activity-related" skeletal markers may be identified, thus, enabling the testing of the hypothesis outlined in Chapter 1.

Secondly, the north of Chile is an area that has been the focus of a great deal of well-documented archaeological research. As part of a valuable source of information regarding the lifestyle of these individuals, the material culture represented by the grave goods associated with these individuals is well preserved and also well documented (Standen, 2003, Muñoz, 2004). A number of publications as well as Master and Doctoral theses on a broad range of anthropological and archaeological topics have also been produced from the analysis of the human remains. However, this is the first systematic study where coastal fishers from Arica are compared with inland agriculturalists settled in the Azapa valley of Arica on the basis of the manifestation of "activity-related" skeletal changes.

Thirdly, the samples were also chosen because there appears to be an occupational continuity through time in the cultural record of those societies that settled in the north of Chile. According to Guillén (1992, 1997) who conducted a comparative study of cranial measurements and epigenetic traits between a number of populations belonging to different time periods in the Azapa Valley, there appears to be a biological continuity of groups spanning from the Archaic period (9000-3700 BP) to the Formative period (3700-1500 BP). This would therefore imply the presence of a single biological group that adapted to living in the region throughout this time. Sutter (2006) also arrived at a similar conclusion when working on the frequency of non-metric dental traits in coastal and inland populations in the Azapa Valley.

Chapter 4:

Methods

Chapter 4: Methods

In this section the methods used to assess sex and age are described along with the general statistical methods used to analyse all markers of occupational stress (MOS). Further detailed information is also given regarding the methods used to collect and analyse enthesophytes, osteoarthritis, spondylolysis, os acromiale and osteochondritis dissecans. Finally, the measurements taken to calculate the robusticity indices as well as the platymeric and platycnemic indices necessary to perform the osteometric analysis are also described.

4.1 Methods of analysis

The analysis of the skeletal samples required two fieldtrips to the Museo Arqueológico San Miguel de Azapa, in Arica. They were carried out during the months of October and November of 2006 and a similar period in 2007. The skeletal material was stored in the Laboratorio de Antropología Física where the analysis took place. All the information and documentation available regarding each individual analysed was noted and saved as a summary sheet (Table 10).

Recording form -Summary Sheet-	
Site	
Skeleton number	
Cultural phase	
Contextual association	
Sex	
Age	

Table 10: Information provided by the Museum's catalogue on each individual analysed

In bioarchaeology, there is no standard recording form for the skeletal changes that may be regarded as "activity-related" that is currently available. Therefore, a recording form was created for the purposes of recording the required information on each specific condition described in Chapter two directly onto a laptop computer. The following sections will cover this information as well as the methods used to assess sex, age and perform the statistical analysis.

4.1.1 Methods to assess sex, age and perform the statistical analysis

The vast majority of the individuals used for this study were sexed and aged after excavation by a number of specialists who were involved in and connected to the post-excavation analysis of the bodies. For instance, Dr Bernardo Arriaza and Dr Vivien Standen (University of Tarapacá), Dr Marvin Allison (Virginia Commonwealth University Service, USA), Dr Sonia Guillén (Centro Mallqui, The Bioanthropology Foundation of Peru) and Dr Arthur Aufderheide (University of Minnesota, USA) were amongst the anthropologists, bioarchaeologists and pathologists in charge of carrying out initial sex and age estimation. According to the written records, direct observation of the external genitalia was possible in a large number of cases due to the excellent state of preservation of the mummified bodies. At times, when preservation was poor, sex was inferred from the direct observation of dimorphic bones such as the innominate bone (Allison and Gerszten, 1982). It was possible to assess age only in the "post-mummification" stage, in other words after being skeletonised and dissected to reveal the skeleton; this then allowed the use of conventional osteological ageing techniques.

Although sex and age had already been assessed for most of the bodies used by the scholars mentioned above, it was decided to reassess these data by applying the same standard sex and age methods to all the skeletons in order to prevent inter-observer error. According to the aims outlined in section 1.2, adult individuals were only used for this study because sub-adults may not have taken part in regular physical activities for long enough to manifest activity-related skeletal changes. The term "adult individual" is used here to refer to the biological and physiological age of the individuals, in other words the biological process of development represented by growth, maturation and degeneration (Gowland, 2006; Samworth and Gowland, 2007). This term of course does not refer to the social age given by these populations to their members as these will vary from one culture to another (Chamberlain, 2006). In the particular case of coastal fishers and inland agriculturalists where there is no ethnographical evidence or any other source of written record, the social aspects of age will probably remain unknown. Hence, adult age was explored taking into consideration a number of skeletal indicators of age that represent skeletal maturation in contemporary populations from which this information is known. These included the obliteration of the sphenoid-basilar suture (age range for fusion 18-25 years) and/or at least one of the third molars had erupted (17-21 years). In the absence of the skull, the degrees of the epiphyseal fusion of the sternal end of the clavicle (16-21 years), epiphyseal plates of the vertebral bodies (18-24 years), and the iliac crest (18-20 years), which represent the final stages of skeletal maturation, were used following Scheuer and Black (2004).

As these reported times of fusion are very variable, with the sphenoid-basilar suture and the sternal end of clavicle representing the last and the first stages of skeletal maturation, all these markers were used whenever possible according to the skeletal elements preserved, in order to differentiate adult age from sub-adult age.
As suggested by Scheuer and Black (2004) there are a number of variables influencing the natural process of growth and development including differences between males and females in terms of skeletal maturation, diet, genetics, and pathological disturbances. Thus, as expected, a number of assumptions had to be made in order to be able to apply these reference standard markers of age based on modern clinical populations to archaeological samples.

(i) Sex

Sex was determined by using a combination of dimorphic aspects of the skull and the pelvis. An example of the recording form can be found in Table 11. Within the skull, the appearance of the nuchal crest, size of mastoid process, the expression of the supra-orbital margin and the glabella, the mental eminence shape and gonial flaring were the chosen diagnostic features following Bass (2005). In the pelvis, the subpubic angle, the ventral arc, the ridge of the ischio-pubic ramus, the greater sciatic notch and the preauricular sulcus were also observed according to Bass (2005). Each individual was therefore assigned to an either “male” or “female” category, according to the overall assessment of all dimorphic features of the skull and the pelvis. No other categories such as “possible female” or “possible male” were created because it was possible to sex most of the skeletons. In exceptional cases where sex assessment was doubtful because of the absence of diagnostic dimorphic skeletal elements, the given sex was based on the original records stated in the identification card for that particular skeleton, which was based on the observation of external genitalia prior to skeletonisation and removal of soft tissues.

Sex estimation		
Bone	Traits	Female - Male
Skull	Nuchal crest	
	Mastoid process	
	Orbital margins	
	Glabella	
	Mental eminence	
	Gonial flaring	
Overall estimation for the skull		
Pelvis	Subpubic angle	
	Ventral arc	
	Ischio-pubic ramus ridge	
	Sciatic notch	
	Pre-auricular sulcus	
Overall estimation for the pelvis		
Note: dimorphic traits of the skull and pelvis from Bass (2005)		

Table 11: Recording form for sex estimation

(ii) Age at death

Age was similarly assessed whenever possible with a combination of methods. The recording form created to collect these data, can be found in Table 12.

Age estimation	
Traits	Y-A (20-34) M-A (35-49) O-A (50+)
Pubic symphysis (Brooks and Suchey, 1990)	
Sternal rib ends (Loth and İşcan, 1989)	
Auricular surface (Lovejoy *et al*., 1985)	
Epiphyseal fusion: clavicle/ iliac crest/ basilar suture/ epiphyseal plates of the vertebral bodies, eruption of 3rd molar/ (Scheuer and Black, 2004)	
Overall age estimation	
Note: age categories from Buikstra and Ubelaker (1994)	

Table 12: Recording form for age estimation

The pelvis and the ribs were observed for degenerative changes and compared with a known aged cast series with a scoring system. The degenerative changes of the pubic symphysis were analysed following Brooks and Suchey (1990) and the sternal rib ends following Loth and İşcan (1989). A set of photographs showing the chronological metamorphosis of the auricular surface of the ilium was also used for comparative purposes to determine age according Lovejoy *et al*. (1985).

An estimated age was given to each feature according to the three age categories described by Buikstra and Ubelaker (1994) (Table 13). Based upon the overall assessment of available data, each individual was assigned a final age category.

Categories	Age
Young Adult (Y-A)	20 – 34 years
Middle Adult (M-A)	35 – 49 years
Old Adult (O-A)	50 + years

Table 13: Age categories used in this study
(Buikstra and Ubelaker, 1994)

(iii) Statistical analysis

The methods used to perform statistical analysis specific for each activity-related skeletal change and osteometric analysis carried out in this study are described in detail in sections 3.6 to 3.11. Statistical analysis common to all skeletal changes involved firstly gathering all data produced in an Excel spreadsheet, and later transferring the data to SPSS 16.0 for Windows, where the statistical analysis was undertaken. The level of statistical significance was always set at $p<0.05$.

Two types of prevalence rate calculations were computed for the five skeletal changes analysed in this study. Following Waldron (2007), true prevalence rates were calculated by determining the ratio of n/N, "n" being the numerator resulting from the total number of osseous elements affected with the condition and "N" the denominator, resulting from the total number of osseous elements present for the particular age and sex category considered. Crude prevalence rates were calculated by determining the ratio of n/N, "n" being the numerator resulting from the total number of individuals affected with the condition, and “N” the denominator, resulting from the total number of individuals sampled, regardless of preservation of specific bone elements.

The lack of consensus and standard methods used in studying “activity” related bone changes prompted the necessity for reporting true and crude prevalence rates in order to provide more opportunities for comparisons with other published data. On the other hand, as crude prevalence rates represent a gross under-estimate of the real prevalence of a pathological condition (Roberts and Cox, 2003:401), all statistical tests performed in this study were based on true prevalence rate calculations, as suggested by Jurmain (1999:229) and Fibiger and Knüsel (2005).

4.2 Enthesophytes

4.2.1 Data collection

Entheses on left and right major upper and lower limb bones were analysed for the presence of enthesophytes. A list of the chosen muscle and tendon attachment sites with their main functions is listed in Table 14. These were selected because they represent the major muscles and tendons attachments that allow movement of the upper and lower limbs, and secondly, as reviewed in Chapter two (section 2.1.6); these are the most frequently used by scholars interested in documenting activity-related bone changes.

4.2.2 Data analysis

There is no agreement to date on how to analyse enthesophytes. This prompted the organisation of the first workshop in musculoskeletal stress markers (MSM) in Coimbra (Portugal) in July 2009, as discussed above. Despite this recent meeting, other attempts have been made to develop standardised recording systems for the study and recording of enthesophytes, as discussed in Chapter two (section 2.1.6). The grading or scoring system developed by Hawkey and Merbs (1995) has been widely used over the past ten years by a large number of European and North American scholars. However, this method as well as others subsequently proposed by Robb (1998) and Mariotti *et al.* (2004) suffer from subjectivity and produce inconsistent data. Recent attempts using three-dimensional techniques to record MSM have been developed by Henderson and Gallant (2007) and Viola *et al.* (2007) with future potential for a more standardised recording system. However, the equipment necessary to apply these techniques is not always accessible.

Limb	Bone	Entheses	Muscle or ligament	Function
Upper	Clavicle	Costal tuberosity	Costo-clavicular ligament	Strengthens the sterno-clavicular joint
	Humerus	Lesser tubercle	*M. subscapularis*	Medial rotation of the arm
		Greater tubercle	*M. supraspinatus* *M. infraspinatus* *M. teres minor*	Abduction and lateral rotation of the arm Abduction and lateral rotation of the arm Abduction and lateral rotation of the arm
		Deltoid tuberosity	*M. deltoideus*	Flexion and medial rotation of the arm
		Medial epicondyle	*M. common flexor origin* *M. pronator teres*	Flexion of the forearm, extension of the hand and fingers Pronation and flexion of the forearm
		Lateral epicondyle	*M. common extensor origin* *M. anconeus*	Extension of the hand and fingers Extension and pronation of the forearm
	Radius	Radial tuberosity	*M. biceps brachii*	Flexion and supination of the forearm
	Ulna	Olecranon	*M. triceps brachii*	Extension of the forearm
		Ulnar tuberosity	*M. brachialis*	Flexion of the forearm
Lower	Os coxa	Ischial tuberosity	*M. semimembranosus* *M. semitendinosus* *M. biceps femoris*	Extension of the hip, flexion of the leg Extension of the hip, flexion of the leg Extension of the hip, flexion of the leg
	Femur	Lesser trochanter	*M. iliacus* *M. psoas major*	Flexion of the hip Flexion of the hip
		Greater trochanter	*M. gluteus minimus* *M. gluteus medius* *M. piriformis* *M. obturator internus* *M. obturator externus*	Abduction and medial rotation of the hip Abduction and medial rotation of the hip Abduction and lateral rotation of the hip Lateral rotation of the hip Lateral rotation of the hip
		Linea aspera	*M. adductor brevis* *M. adductor magnus* *M. gluteus maximus* *M. vastus medialis* *M. vastus lateralis*	Adduction, extension and flexion of the hip Adduction, extension and flexion of the hip Extension, abduction and lateral rotation of the hip Extension of the knee Extension of the knee
	Tibia	Tibial tuberosity	*M. quadriceps femoris*	Extension of the knee
		Soleal line	*M. soleus*	Flexion of the ankle and foot
	Calcaneus	Calcaneal tuberosity	Achilles tendon	Flexion of the foot

Table 14: Muscles and tendons chosen for the analysis of enthesophytes

In order to prevent subjectivity and in line with recent work carried out by Groves (2006) , Alves Cardoso (2008) and Henderson (2009), the major long bones from the left and right upper and lower limbs were macroscopically examined for the presence of enthesophytes as a dichotomous variable (present/absent). An example of the recording form used to gather this information can be found in Table 15.

Enthesophytes		Right side	Left side
Bone	Enthesis		
Clavicle	Costal tuberosity		
Humerus	Lesser tubercle		
	Greater tubercle		
	Deltoid tuberosity		
	Medial epicondyle		
	Lateral epicondyle		
Radius	Radial tuberosity		
Ulna	Olecranon		
	Ulnar tuberosity		
Os coxae	Ischial tuberosity		
Femur	Lesser trochanter		
	Greater trochanter		
	Linea aspera		
Tibia	Tibial tuberosity		
	Soleal line		
Calcaneus	Calcaneal tuberosity		
Note: a comment was made if the bone part where the enthesis is present was present, absent or unavailable			

Table 15: Recording form for enthesophytes

An enthesophyte was recorded as positive or “YES” (score of 1) when changes at the muscle insertion were present as shown in Fig 43. Negative cases or “NO” (score of 0) meant that the enthesis did not show the changes. Bones “Unavailable” for study were recorded as such if the enthesis was unavailable for observation due to the presence of soft tissue still attached to the enthesis, or if a bone or bones were absent, or if there was localised trauma or a pathological condition at the insertion sites.

Figure 43: Mo1/6 T41 showing an enthesophyte at the *M. triceps* insertion of the left ulna

True prevalence rates were calculated for each enthesis, which in total covered the major regions of the upper and lower limbs, and the shoulder, elbow, hip, knee and ankle joints.

Following these preliminary considerations and taking into consideration that muscles do not work separately or individually but synergistically and in groups, it was decided that each separate enthesis would be grouped together with others that performed a similar and/or mutual function or action within an anatomical region of the body (Table 16). This grouping facilitated the comparison of the data for OA of the joints, also grouped in a similar fashion.

The initial data analysis therefore consisted of calculating true and crude prevalence rates for enthesopathy according to the five chosen anatomical areas (shoulder, elbow, hip, knee and ankle) for both coastal Chinchorros and inland agriculturalists. Following this, analysis focused on comparing the frequency of enthesopathy, according to sex, between the two groups. This analysis was divided in two parts, firstly focusing on an intra-group correlation of the condition with age, and secondly, focusing on inter-group sex comparisons according to age. Finally, the analysis focused on enthesophytes and laterality but only at an intra-group level.

Limb	Joint	Bone	Entheses
Upper	Shoulder	Clavicle	Costal tuberosity
		Humerus	Lesser tubercle
			Greater tubercle
			Deltoid tuberosity
	Elbow	Humerus	Medial epicondyle
			Lateral epicondyle
		Radius	Radial tuberosity
		Ulna	Olecranon
			Ulnar tuberosity
Lower	Hip	Os coxa	Ischial tuberosity
	Knee	Femur	Lesser trochanter
			Greater trochanter
			Linea aspera
		Tibia	Tibial tuberosity
			Soleal line
	Ankle	Calcaneus	Calcaneal tuberosity

Table 16: Grouped entheseal areas chosen for the analysis of enthesophytes

4.2.3 Statistical methods

Due to the categorical nature of the data, a series of Pearson Chi-square tests were performed with the objective of examining whether there was any relationship or association between enthesophytes and joints, enthesophytes and sex, enthesophytes and age, and enthesophytes and laterality. Intra and inter-group comparisons were carried out using true prevalence value rates only. The Fisher's exact test was calculated in cases where the assumption of expected values greater than five (>5) was not met to calculate the Chi-square test. Following this, a Kendall's tau-b correlation test was also performed in order to determine if increasing age was correlated with an increasing prevalence of MSM. Finally, as a general practice, a two-tailed significance test was considered for all statistical tests used.

4.3 Osteoarthritis

The analysis of joints for the presence of OA showed that in the majority of cases, the hyaline cartilage remained mummified and attached to the bone, which allowed direct observation of its degeneration and erosion along with pathological changes of the underlying subchondral bone as shown in Fig 44. However, preservation of cartilage compromised the observation of bone surfaces.

As the loss of articular cartilage is the first sign of OA, and often shows the most consistent and obvious gross osteoarthritic pathological changes (Jurmain, 1999), its direct observation presented a unique opportunity that neither clinicians nor bioarchaeologists can usually experience. The remarkable condition in which these mummified human remains were preserved could lead to future advances in the study of OA involving the identification of vulnerable areas subjected to loading within the articular cartilage, identification of pathological changes such as erosion and degradation, as well as recognising how the subchondral bone responds to such disruptions.

Figure 44: Az140 TXPB6 Left radius showing loss of cartilage with porosity of the underlying subchondral bone

4.3.1 Data collection

Both sides of the major joints of the upper and lower limbs were analysed for the presence of OA because the pattern of symmetry can be a useful indicator of relative functional stress according to Jurmain (1980). These appendicular joints are described in Table 17.

Limb	Region	Joint
Upper	Shoulder	Acromio-clavicular
		Gleno-humeral
	Elbow	Humero-ulnar
		Humero-radial
		Radio-ulnar
Lower	Hip	Coxo-femoral
	Knee	Femoro-tibial
		Femoro-patellar
	Ankle	Tibio-talar

Table 17: Joints analysed for the presence of OA

The vertebral column was not analysed for the presence of OA because of the following two reasons. Firstly, as discussed above, according to a study conducted by Knüsel *et al.* (1997) on degenerative changes in the vertebral column of three different social groups of male individuals recovered from the late medieval cemetery of St. Andrew Fishergate in York, the authors found that there was no statistical significance in the patterns of spinal degenerative changes between the groups in the cemetery. As spinal changes indicate mechanical forces placed upon the vertebral column associated with bipedalism, the authors concluded that this region of the body may not be a suitable part of the skeleton to study degenerative conditions such as OA and consequently the effects of activity patterns. Secondly, the vertebral column has been studied for the presence of OA among coastal fishers and inland agriculturalists by a number of authors including Allison (1984), Arriaza (1995a, 2003) and Muñoz (2004). In addition to the conclusion arrived by Knüsel *et al.* (1997), the lack of systematic analysis of osteoarthritic changes affecting other areas of the body of these populations, prompted the necessity to turn the focus of attention to joints not previously studied. Hence, by addressing both upper and lower limbs joints for the presence of this condition further new data will be provided.

4.3.2 Data analysis

The methods used for recording OA in skeletal populations vary enormously. Unlike clinicians who rely on radiographs, bioarchaeologists diagnose the condition by direct observation of the bone surface. Thus, the diagnosis of OA is based on the presence of osteophytes, porosity and eburnation, although eburnation is, according to Jurmain (1999), the only pathognomonic indication of the condition in skeletal remains. Rogers and Waldron (1995) suggested that in its absence, two other features such as marginal osteophytes and changes in the normal contour shape of the joint or pitting should also be present.

In summary, and in line with recent work carried out by Groves (2006), Alves Cardoso (2008) and Henderson (2009) on skeletal markers of occupation, OA was analysed by direct macroscopic inspection as a dichotomous variable (present/absent). The condition was diagnosed as present following the criteria of Rogers and Waldron (1995). Eburnation was present when the bone had been converted into a dense smooth substance resembling ivory as a result of bone-to-bone contact as observed in Fig 45.

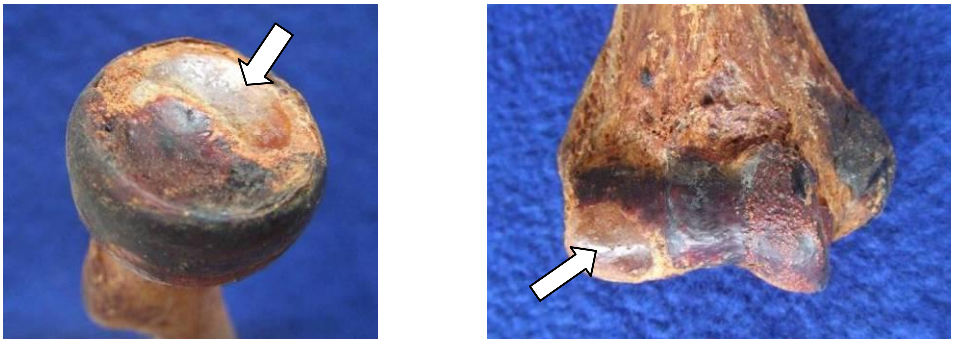


Figure 45: Mo1/6 T17 showing eburnation of the right radial-humeral joint

Osteophytes were defined as the presence of new bone on or around the joint surface, varying from small protuberances to florid bone outgrowths. Porosity was defined as any change from small clusters of perforations to considerable holes in the joint surface, and contour change as any pathological alteration to the normal aspect of the joint morphology. Examples of these features are depicted in Figs 46 and 47.

Figure 46: Mo1/6 TXVII(5) showing osteophytes and porosity on both patellae

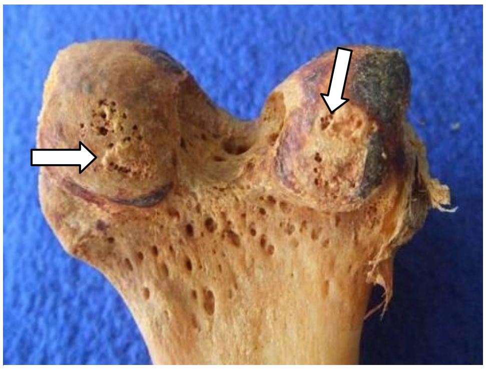


Figure 47: Az71 T16 showing porous lesions and osteophytes on the left femur

While Jurmain (1999) also emphasised that eburnation is the most reliable pathognomonic criterion for diagnosing the skeletal presence of OA, in contrast to the opinion of Rogers and Waldron (1995), eburnation among these populations also appeared to be very subtle as it was present in only six skeletons Az140 T19, AZ140 T77, AZ140 T112A, Mo1/6 T17, and Mo1/6 T32 affecting six of their joints, i.e. one joint for each skeleton. For this reason, it was considered that the Rogers and Waldron (1995) methodology was the most appropriate for the purpose of this study as it would cover a wide range of bony changes that are also indicative of OA. This would allow future comparative studies where researchers had used the same diagnostic criteria. As the joints examined consisted of two articular surfaces, and the changes observed may not always be the same on both surfaces of one joint, it was decided primarily to record them as separate surfaces. Thus, following a similar path of analysis as that of MSM, a joint was recorded as positive or "YES" for OA (score of 1) when at least one surface showed the condition. In other words, negative or "NO" meant that both surfaces did not show changes indicative of OA (score of 0). Joints "Unavailable" for study were scored as such if at least one or both surfaces were unavailable for observation due to the presence of soft tissues still attached near to the articular area, as well as when a bone or bones were absent. In addition, OA secondary to trauma, secondary to another pathological condition, or ankylosis of the joint meant the joint was "Unavailable" for observation. Positive and negative scores were counted as dichotomous variables and true prevalence rates were calculated for each articular surface considered, which in turn constituted the major joints of the shoulder, elbow, hip, knee and ankle joints. An example of the recording form used to gather this information can be found in Table 18.

The initial data analysis therefore consisted in calculating true and crude prevalence rates of OA according to the five chosen joints (shoulder, elbow, hip, knee and ankle) for both coastal Chinchorros and inland agriculturalists. Following this, and as in previous sections, the analysis focused on comparing osteoarthritis according to sex between the groups. This analysis was divided in two parts, firstly focusing on intra-group correlations of the condition with age, and secondly focusing on inter-group sex comparisons according to age. Finally, analysis focused on OA and laterality but only at the intra-group level.

OA and OD Joint	Right side	Left side
Acromio-clavicular		
Gleno-humeral		
Humero-radial		
Humero-ulnar		
Radio-ulnar		
Coxo-femoral		
Femoro-tibial		
Femoro-patellar		
Tibio-talal		
Note: a comment was made if OA and OD were present, absent or the joint was not preserved to observe. Note: a comment was made if, in OD, loose bodies were recovered free and movable or remained attached to the defect		

Table 18: Recording form for osteoarthritis and osteochondritis dissecans

4.3.3 Statistical methods

Due to the categorical nature of the data, a series of Pearson Chi-square tests were performed with the objective of examining whether there was any relationship or association between OA and joints, OA and sex, OA and age, and OA and laterality. Intra and inter-group comparisons were carried out using true prevalence values only. In cases where the assumption of expected values greater than five (>5) was not met to calculate the Chi-square test, a Fisher's exact test was used instead. A Kendall's tau-b correlation test was also performed in order to determine if increasing age was followed by increasing prevalence rates of osteoarthritis as reported in the clinical (Jones *et al.*, 2002; Andrianakos *et al.*, 2006) and bioarchaeological literature (Bridges, 1992; Jurmain and Kilgore, 1995; Groves, 2006; Alves Cardoso, 2008). Finally, as a general practice, a two-tailed significant test was considered in all statistical tests used.

4.4 Spondylolysis

4.4.1 Data collection

As discussed in section 2.3.2, there is no standard method to record spondylolysis. For this reason a recording form was created for this purpose. An example of this can be found in Table 19.

Spondylolysis	L1	L2	L3	L4	L5
Present/Absent/Unavailable					
Note: a comment was made if the lesion was complete, incomplete or healed					

Table 19: Recording form for spondylolysis

4.4.2 Data analysis

All lumbar vertebrae, including the sixth where present, were observed by direct macroscopic inspection for the presence of the condition, despite the fact that L5 appears to be the most affected vertebra (Arriaza, 1997; Merbs 2002b; Fibiger and Knüsel, 2005; Ruiz-Cotorro *et al*., 2006; Gregory *et al*., 2007).

Following a similar path of analysis as that of MSM and OA, spondylolytic lesions were recorded according to whether the condition was present or absent. A vertebra was recorded as positive, present or “YES” for spondylolysis (score of 1) when at least one pars interarticularis showed signs of separation as seen in Fig 48. Negative, absent or “NO” meant that both pars interarticularis did not show indications of separation, cracks or changes indicative of spondylolysis (score of 0). Vertebrae “Unavailable” for study were scored as such if essential anatomical areas such as the neural arch and pars interarticularis were damaged, pathological, absent or unavailable for observation due to the presence of soft tissues still attached to adjacent areas. Positive and negative scores were counted as dichotomous variables, and true and crude prevalence rates were calculated.

Further descriptive information on the condition was also provided following Merbs (2002a) and according to whether the separation was complete or incomplete. These categories and their variants are summarised in Table 4 of section 2.3.6 of this chapter. The main idea behind adopting this classification was not to provide a typological description of the condition but to present information that could be useful in future studies.

The initial data analysis therefore consisted of calculating true and crude prevalence rates for spondylolysis according to each lumbar vertebra for both coastal Chinchorros and inland agriculturalists. Following this, and as in previous sections, analysis focused on intra-group and inter-group comparisons according to sex. Finally, analysis focused on spondylolysis according to age.

Figure 48: Az71 T601 showing complete separation at the pars interarticularis of L5

4.4.3 Statistical methods

Due to the categorical nature of the data, a series of Pearson Chi-square tests were performed with the objective of examining the association between spondylolysis and vertebrae, spondylolysis and sex, and spondylolysis and age. Intra and inter-group comparisons were carried out using true prevalence rate values only. The Fisher's exact test was calculated in cases where the assumption of expected values greater than five (>5) was not met to calculate the Chi-square test. Furthermore, as a general rule a two-tailed significant test was considered in all statistical tests used.

Unlike osteoarthritis or enthesophytes, spondylolysis is not an age-related condition and therefore its correlation with increasing age across the three age categories is irrelevant and does not necessarily provide additional information. Therefore, no age correlation test was performed. Furthermore, as discussed in section 2.3.4, the onset of spondylolysis starts in childhood and early adulthood and so considering the age at death of individuals as the onset age of spondylolysis, as usually happens in bioarchaeology (Merbs, 1996a), does not necessarily reflect the age the lesion took place, thus contributing to bias in any comparative analysis.

4.5 Os acromiale

4.5.1 Data collection

There is no standard method to record os acromiale. For this reason a recording form was created for this purpose, which can be found in Table 20.

Os acromiale	Right acromion	Left acromion
(Present/Absent/Unavailable)		

Table 20: Recording form for os acromiale

4.5.2 Data analysis

All available acromia were observed by direct macroscopic inspection. Following a similar path of analysis as that of MSM, OA, spondylolysis and OD, os acromiale was recorded according to whether the condition was present or absent. Being present, positive or "YES" meant that a fragment had resulted from the non-fusion of the acromion of the scapula (Fig 49) (score of 1).

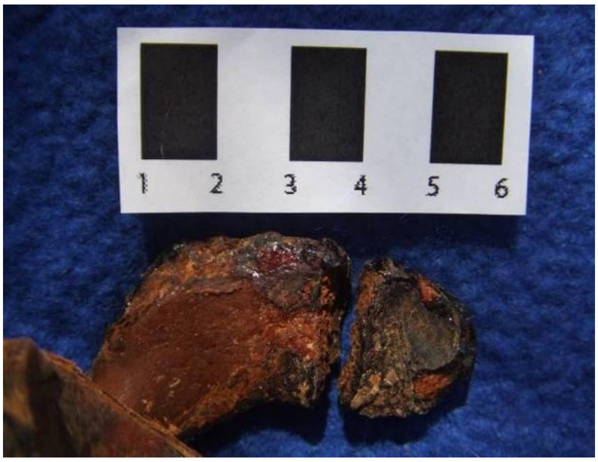


Figure 49: Mo1 T19 showing os acromiale on the right acromion

Furthermore, as bilateral involvement adds confusion to the overall prevalence of os acromiale, the condition was scored present only once if found affecting an individual either unilaterally or bilaterally. Negative or "NO" meant that the condition was absent and the acromion did not show indications of non-fusion (score of 0). The condition was also scored as “NO” when the free fragment was not fused because it belonged to a normal immature acromion of a young individual. Acromia “Unavailable” for study were scored as such if the scapula was absent or if essential anatomical areas such as the distal end of acromion were missing, damaged, pathological, or unobservable due to the presence of soft tissues still attached to adjacent areas. Positive and negative scores were counted as dichotomous variables (present/absent).

The initial data analysis consisted of calculating true and crude prevalence rates for os acromiale for both samples. Following this, and as in previous sections, the analysis focused on intra-group and inter-group comparisons according to sex. Finally, analysis focused on os acromiale according to age.

4.5.3 Statistical methods

Due to the categorical nature of the data, a series of Pearson Chi-square tests were performed with the objective of examining the association between os acromiale and acromion, os acromiale and laterality, os acromiale and sex, and os acromiale and age. Intra and inter-group comparisons were carried out using true prevalence values only. The Fisher’s exact test was calculated in cases where the assumption of expected values greater than five (>5) was not met to calculate the Chi-square test. Furthermore, as a general rule, a two-tailed significant test was considered in all statistical tests used.

Unlike osteoarthritis or enthesophytes, os acromiale shares with spondylolysis the attribute that it is not an age-related condition and therefore its correlation with increasing age across the three age categories is irrelevant and does not necessarily provide additional information. Therefore, no correlation test was performed.

4.6 Osteochondritis dissecans

4.6.1 Data collection

As discussed in section 2.5.3, osteochondritis dissecans can be present in any joint of the body. Therefore, following a similar approach to that explained in section 4.3.2 for osteoarthritis, both sides of the major joints of the upper and lower limbs were analysed for the presence of osteochondritis dissecans. These are described in Table 17.

There is no standard recording form for the condition to date. An example of the recording form developed to gather this information, can be found in Table 18.

4.6.2 Data analysis

A joint was recorded as positive or "YES" for osteochondritis dissecans (score of 1) when the joint presented a scoop-like depression on the articular surface as described by Aufderheide and Rodríguez-Martín (1998:81-3) and Ortner (2003:351-2). Joint surfaces were scored as 0 when they did not show changes indicative of the condition. "Unavailable" for study was scored as such if their surfaces were unavailable for observation due to the presence of soft tissues still attached to the articular area, as well as when bones were absent. Positive and negative scores were counted as dichotomous variables (present/absent). The analysis was performed according to which joint surface was affected documenting whether the condition was unilateral, bilateral or if loose bodies were recovered free and movable, or remained attached to the lesion created.

4.6.3 Statistical methods

Positive and negative scores were counted as dichotomous variables (present/absent). True and crude prevalence rates were calculated for the joints affected by the condition, but no further statistical analysis was carried out because, as will be shown later in the results, only one case of osteochondritis dissecans was found in 175 skeletons (two femoro-tibial joints of 314 available for study), thus making it impossible to perform any further comparative analysis.

4.7 Osteometric analysis

The contribution of osteometry to the reconstruction of activity patterns in human skeletal remains was highlighted in section 2.6.2 of Chapter two. For this reason, external diaphyseal measurements were taken on both sides of the major upper and lower limb bones with the intention of obtaining four indices for comparison between the two samples.

4.7.1 Data collection

Ten measurements were taken on both right and left humeri, femora and tibiae (Table 21). These bones were chosen because according to Knüsel (2007:104), the upper limb bones are normally involved in voluntary activities such as manipulation of objects and tools and therefore are more likely to reveal information on activity patterns. The lower limb bones, on the other hand, are linked to ambulatory activities and, although they are not strictly speaking connected with volitional activities per se, they have been commonly used as activity-related markers to determine patterns of mobility. The femur in particular has been the bone most frequently used due to its robusticity and high degree of preservation in archaeological contexts (Ruff *et al*., 1993).

Measurements were taken according to the descriptions provided by Bass (2005) using standard osteometric equipment. An osteometric board was used to measure lengths, an electronic calliper to measure diameters and a measuring tape for bone circumferences. Measurements were recorded to the nearest millimetre and uploaded directly into an excel spreadsheet. An example of the recording form can be found in Table 22.

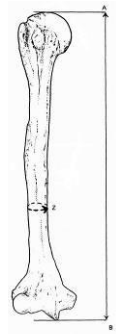
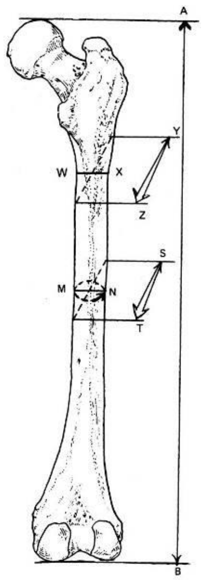
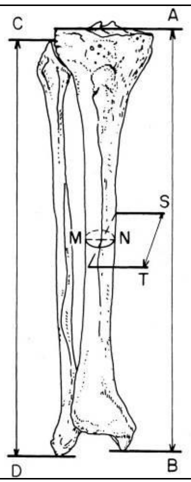
Bone	Measurement	Definition	Marks	
Humerus	Maximum length	Distance from the most superior point on the head of the humerus to the most inferior on the trochlear	(A-B)	
	Circumference	Least circumference of the shaft taken at about the second one-third distal to the deltoid tuberosity	(Z)	
Femur	Maximum length	Distance from the most superior point on the head of the femur to the most inferior point on the distal condyles	(A-B)	
	Antero-posterior diameter at midshaft	Distance between anterior and posterior surfaces at the midpoint of the diaphysis	(S-T)	
	Medio-lateral diameter at midshaft	Distance between the medial and lateral surfaces at midshaft, measured perpendicular to the previous measurement	(M-N)	
	Antero-posterior diameter subtrochanteric	Distance between anterior and posterior surfaces at the proximal end of diaphysis, measured perpendicular to the mediolateral diameter	(Y-Z)	
	Medio-lateral diameter subtrochanteric	Distance between mediolateral surfaces of the proximal end of the diaphysis at the point of its greatest lateral expansion below the base of the lesser trochanter	(W-X)	
Tibia	Maximum length	Distance from the superior articular surface of the lateral condyle to the tip of the medial malleolus	(A-B)	
	Antero-posterior diameter at nutrient foramen	Maximum antero-posterior diameter of the shaft at the level of the nutrient foramen (at about the proximal end one-third)	(S-T)	
	Medio-lateral diameter at nutrient foramen	Maximum transverse diameter at the level of the nutrient foramen (at right angles to the previous measurement)	(M-N)	

Table 21: External long bone measurements (from Bass, 2005)

Osteometric analysis			
Bone	Measurements	Right side	Left side
Humerus	Max Length		
	Ant-Post Diameter at Midshaft		
	Med-Lat Diameter at Midshaft		
	Circumference		
Femur	Max Length		
	Ant-Post Diameter at Midshaft		
	Med-Lat Diameter at Midshaft		
	Ant-Post Diameter at Subtrochanteric level		
	Med-Lat Diameter at Subtrochanteric level		
Tibia	Max Length		
	Ant-Post Diameter at Nutrient foramen		
	Med-Lat Diameter at Nutrient foramen		
Note: a comment was made if the bone was broken, missing or unavailable for measurement Note: measurements were taken according to the descriptions provided by Bass (2005)			

Table 22: Recording form for the osteometric analysis

4.7.2 Data analysis

The lengths, diameters and circumferences taken on the humeri, femora and tibiae were used to calculate four postcranial indices, the humeral robusticity index (HR), the femoral robusticity index (FR), the femoral platymeric index (FP) and the tibial platycnemic index (TP). The formulae used to calculate the indices are shown in Table 23.

Index	Formula
Humeral robusticity (HR)	$\frac{\text{least circumference of shaft x 100}}{\text{maximum length of humerus}}$
Femoral robusticity (FR)	$\frac{\text{antero-posterior + medio-lateral diameter of midshaft x 100}}{\text{bicondylar (physiological) length}}$
Femoral platymeric (FP)	$\frac{\text{subtrochanteric antero-posterior diameter x 100}}{\text{subtrochanteric medio-lateral diameter}}$
Tibial platycnemic (TP)	$\frac{\text{medio-lateral nutrient diameter x 100}}{\text{antero-posterior nutrient diameter}}$

Table 23: Post-cranial indices (from Bass, 2005)

The robusticity indices are indicative of the dimensions or proportions of the shafts of these bones (Bass, 2005:148, 225; Knüsel, 2007:104; Stock and Shaw, 2007). As diaphyseal dimensions and proportions are influenced by physical activity (Knüsel,

2000) robusticity indices represent excellent comparative tools of activity-related changes.

The platymeric and platycnemic indices are indicative of the degree of antero-posterior and medio-lateral flatness of these bones (Bass, 1995; Larsen, 1997). According to Bass (2005), values of femoral platymeric index range from ≤ 84.9, eurymeric (85.0 – 99.9) and stenomeric (≥ 100.0). Platicnemic values of the tibia rage from hyperplaticnemic (≤ 54.9), platicnemic (55.0 – 62.9), mesocnemic (63.0 – 69.9) and euricnemic (≥70.0). The extent of diaphyseal flattening is thought to be related to physical activity and workload (Brock and Ruff, 1988; Jackes *et al.,* 1997). Low platymeric and platicnemic values are generally found in more mechanically stressed populations (Larsen, 1997).

Only non-pathological bones of the upper and lower limbs were used for measurement. In other words, a measurement was recorded as "Unavailable" if the bone was absent, broken, pathological, had mummified tissue still attached to the bone that prevented the measurement to be taken or, if as observed in numerous occasions, the nutrient foramen (necessary for calculating the tibial platycnemic index) was not visible. If a bone was unavailable for measurement then the index for that particular bone was impossible to calculate and therefore eliminated from analysis.

Analysis first focused on comparing intra-group and inter-group laterality. In other words, right and left side indices were observed for the presence of any side dominance. According to a number of studies, bilateral asymmetry of the bones should reflect differences in mechanical loads placed upon the limbs and therefore could be used as interpretation of behaviour in the past (Stock and Pfeiffer, 2004; Wanner *et al.*, 2007). Secondly, as in previous sections, analysis focused on comparing indices according to sex. Intra-site and inter-site comparisons were carried out as stated in the objectives. Finally, osteometric analysis was carried out according to age but only at the intra-group level.

4.7.3 Statistical methods

The four above-mentioned indices were calculated for the right and left side of the body. Descriptive statistics were carried out in order to obtain the mean, the minimum and maximum values, and standard deviation.

A Kolmogorov-Smirnov test was performed in order to examine if the assumption of normal distribution was met. Whenever data presented a normal distribution, a series of t-tests were calculated with the objective of comparing the differences between sample means. Thus, a dependent or paired t-test was calculated according to Field (2005) when these means came from the same group of people, for instance when the objective was to explore patterns of side dominance within individuals of the same group. An independent t-test was calculated to observe mean differences between individuals from different sites.

When data presented a non-normal distribution, instead of using the dependent t-test, the non-parametric Wilcoxon signed-rank statistical test was employed, according to Field (2005). Similarly, when the independent t-test was impossible to calculate due to a non-normal distribution of data, the Mann-Whitney U test was used instead. Furthermore, it was ensured that the samples also complied with another assumption necessary to perform the t-test, homogeneity of variance. This was done by dividing the maximum variance by the minimum variance of each index. If the result was less than two then the assumption was met.

Finally, a Pearson correlation test was performed in order to observe any possible relationship between ageing and changes in external bone dimensions. Kendall tau-b was used instead when the distribution violated the assumption of a normal distribution.

Chapter 5:

Results

Chapter 5: Results

This chapter discusses the results obtained from the comparisons between coastal fishers and inland agriculturalists according to statistical analysis of enthesophytes, osteoarthritis, spondylolysis, os acromiale, osteochondritis dissecans, and osteometric analysis in the same order as they were discussed in Chapter two.

5.1 Sex and age

It was possible to sex and age all skeletons. Sex assessment coincided 100% with that carried out during initial analysis in the 1970's and 1980's (see section 3.1) by scholars who excavated the mummies. On the other hand, age assessment did not always match to that estimated by others in previous years and, therefore, it was decided that, in these cases, the chosen age category would be that resulting from the methods used and described in Chapter three. Table 24 shows the final sample composition of coastal fishers and inland agriculturalists according to sex and age and Figs 50 and 51 provide a visual representation of the information included in this table.

Sex	Age	Coastal fishers				Total	Inland agriculturalists			Total
		Mo1	Mo1-5	Mo1-6	Quiani7		Az71	Az140	Az141	
Females	Y-A	9	0	10	0	19	8	13	1	22
	M-A	8	1	4	1	14	9	14	3	26
	O-A	2	0	2	0	4	4	10	0	14
	Total	19	1	16	1	37	21	37	4	62
Males	Y-A	13	1	6	0	20	3	7	4	14
	M-A	7	1	6	0	14	6	12	3	21
	O-A	0	0	3	1	4	1	2	0	3
	Total	20	2	15	1	38	10	21	7	38
Total		39	3	31	2	75	31	58	11	100

Table 24: Sample composition of coastal and inland groups

In summary, a total of 175 skeletons were used for this study, 75 belonging to coastal fishers and 100 to the inland agriculturalists. Although a fairly equal number of individuals of both sexes were available from both skeletal samples, statistical analysis showed that age at death was not normally distributed ($p<0.001$). Coastal and inland groups had a low number of older adult individuals, thus as shown in sections 5.4.3 and 5.5.3 of this chapter, a number of comparisons were not possible to be carried out.

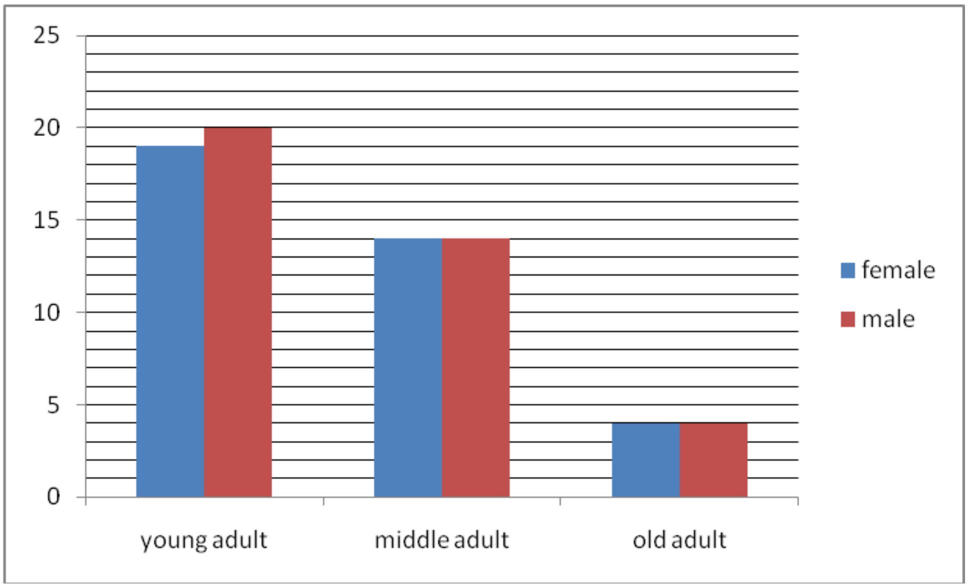


Figure 50: Frequency distribution of coastal fishers

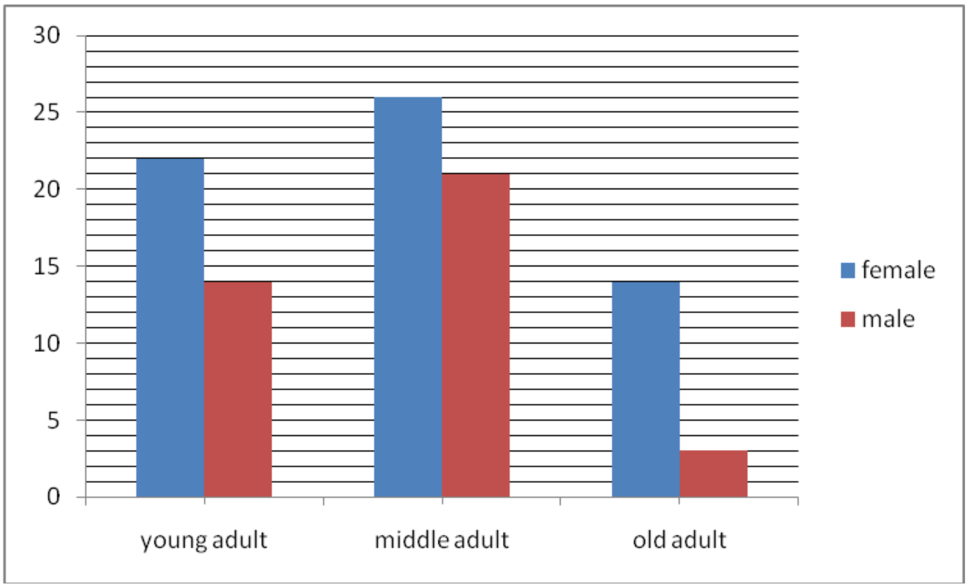


Figure 51: Frequency distribution of inland agriculturalists

Chamberlain (2006) and Waldron (2007) emphasised that the demographic profile of a given archaeological population should be expected to be structured with a high number of deaths at both extreme age categories (juveniles and old adults). This phenomenon was not found among coastal fishers and inland agriculturalists.

According to Chamberlain (2006) it is widely accepted that current ageing techniques employed by bioarchaeologists contribute to underage older skeletons, thus reducing the number of old adult individuals present in the population. It is therefore possible that the relatively fewer individuals in the older age categories are the result of this methodological bias.

5.2 Enthesophytes

The raw data on enthesophytes for both populations can be found in Appendix 1.

The true overall prevalence rate for enthesophytes was 60.1% (2,025/3,367) of entheseal areas affected from both coastal and inland groups. In the former group, 57.8% (588/1,018) of entheses were affected by the condition, and in the inland group, 61.2% (1,437/2,349) of entheses were affected, giving a coastal/inland frequency ratio of approximately 1:1.

Crude prevalence rates, on the other hand, resulted in 98.7% (74/75) of individuals affected with entheseal areas available for study. In the inland group, 100% (100/100) of individuals with entheseal areas available for study were affected by the condition.

Examples of enthesophytes found in both skeletal populations are shown in Figs 52-53.

Figure 53: Az140 T56 showing enthesophyte formation at the *M. common extensor origin* and *M. anconeus* insertion of the right humerus

Figure 52: Mo1 T27C13 showing an enthesophyte formation at the *M. soleus* insertion of the left tibia

5.2.1 Enthesophytes according to joint

Table 25 shows the prevalence rate obtained from the analysis of enthesophytes according to entheseal areas in both groups.

MSM	Coastal fishers				Inland agriculturalists				X^2 (df=1)	p
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	113/228	49.6	44/59	74.6	308/586	52.6	92/100	92.0	0.591	>0.05
Elbow	146/280	52.1	53/61	86.9	347/721	48.1	83/99	83.8	1.301	>0.05
Hip	63/80	78.8	38/48	79.2	111/145	76.6	63/79	79.7	0.142	>0.05
Knee	260/423	61.5	66/71	93.0	600/812	73.9	96/99	97.0	20.309	<0.001
Ankle	6/7	85.7	4/5	80.0	71/85	83.5	45/53	84.9	Fisher	>0.05
Total	588/1018	57.8	74/75	98.7	1437/2349	61.2	100/100	100.0	3.455	0.035

Table 25: Prevalence rates for enthesophytes according to entheseal areas

Note: right and left hand side enthesophytes as well as all age categories and sexes were pooled. True prevalence represents the (n) number of entheses affected compared to (N) or number of entheses available for study. Crude prevalence rates reflect (n) the number of individuals affected according to (N) the number of individuals with entheses available for study. Chi-square was performed on true prevalence values.

Chi square analysis revealed that the enthesophytes located at the knee showed a significant difference in frequency between both groups. Enthesophytes located at the shoulder, the elbow, the hip and the ankle did not show a statistical difference p>0.05; the latter frequencies were calculated using Fisher's exact test as the coastal group did not have sufficient number of entheses necessary to perform the comparison. Chi-square analysis based on total prevalence rates revealed that inland agriculturalists were significantly more affected by enthesophytes than coastal fishers X^2=3.455 (df =1) p<0.05.

5.2.2 Enthesophytes according to sex

In this section, true and crude prevalence rates of enthesophytes were calculated intra-group and inter-group according to sex. Intra-group sex comparisons among coastal fishers (Table 26) revealed significant differences at the shoulder, elbow and hip. Chi-square analysis based on total prevalence rates revealed that males were significantly more affected by enthesophytes than the females X^2=5.510 (df =1) p<0.05.

Intra-group sex comparisons among the inland agriculturalists (Table 27) revealed that 90% of the joints did not show differences in the manifestation of enthesophytes, suggesting a fairly equal distribution of the condition between the sexes. The only exception was the knee joint, where males were significantly more affected.

MSM	Coastal fishers								X^2 (df=1)	p
	Female				Male					
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	45/107	42.1	19/27	70.4	68/121	56.2	25/32	78.1	4.543	0.035
Elbow	58/132	43.9	25/28	89.3	88/148	59.5	28/33	84.8	6.735	0.009
Hip	35/39	89.7	22/25	88.0	28/41	68.3	16/23	69.6	5.496	0.019
Knee	129/216	59.7	34/36	94.4	131/207	63.3	32/35	91.4	0.566	>0.05
Ankle	1/2	50.0	1/2	50.0	5/5	100.0	3/3	100.0	Fisher	>0.05
Total	268/496	54.0	37/37	100.0	320/522	61.3	37/38	97.4	5.510	0.022

Table 26: Prevalence rates for enthesophytes according to sex (Coastal group)

Note: both right and left hand sides as well as all age categories were pooled. True prevalence is the (n) number of entheses affected according to (N) the number of enthesophytes available for study. Crude prevalence rates are (n) the number of individuals affected compared to (N) the number of individuals with entheses available for study. Chi-square analysis was performed on true prevalence values.

MSM	Inland agriculturalists								X^2 (df=1)	p
	Female				Male					
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	197/367	53.7	58/62	93.5	111/219	50.7	34/38	89.5	0.493	>0.05
Elbow	216/464	46.6	51/62	82.3	131/257	51.0	32/37	86.5	1.295	>0.05
Hip	62/87	71.3	36/47	76.6	49/58	84.5	27/32	84.4	3.387	>0.05
Knee	365/514	71.0	60/62	96.8	235/298	78.9	36/37	97.3	6.021	0.014
Ankle	51/58	87.9	33/37	89.2	20/27	74.1	12/16	75.0	Fisher	>0.05
Total	891/1490	59.8	62/62	100.0	546/859	63.6	38/38	100.0	3.250	>0.05

Table 27: Prevalence rates for enthesophytes according to sex (Inland group)

Note: both right and left hand sides as well as all age categories were pooled. True prevalence is (n) the number of entheses affected compared to (N) the number of enthesophytes available for study. Crude prevalence is (n) the number of individuals affected compared to (N) the number of individuals with entheses available for study. Chi-square analysis was performed on true prevalence values.

Inter-group sex comparison (Table 28) suggested that coastal and inland females showed more variation in the patterning and distribution of enthesophytes compared to the males. Chi-square analysis based on total true prevalence rates revealed that female agriculturalists were significantly more affected by enthesophytes than coastal females X^2=5.092 (df =1) p<0.05. Males of both groups on the other hand, showed a highly significant difference only at the knee joint and non-significant differences at the remaining entheseal areas. Chi-square analysis based on total true prevalence rates of entheses analysed also revealed no significant differences between both groups X^2=0.709 (df =1) p>0.05

Sites		Female				Male			
		True n/N	%	x^2 (df=1)	p	True n/N	%	x^2 (df=1)	p
Shoulder	Coastal Valley	45/107 197/367	42.1 53.7	4.478	0.037	68/121 111/219	56.2 50.7	0.950	>0.05
Elbow	Coastal Valley	58/132 216/464	43.9 46.6	0.282	>0.05	88/148 131/257	59.5 51.0	2.724	>0.05
Hip	Coastal Valley	35/39 62/87	89.7 71.3	5.190	0.038	28/41 49/58	68.3 84.5	3.643	>0.05
Knee	Coastal Valley	129/216 365/514	59.7 71.0	8.860	0.003	131/207 235/298	63.3 78.9	14.852	<0.001
Ankle	Coastal Valley	1/2 51/58	50.0 87.9	Fisher	>0.05	5/5 20/27	100.0 74.1	Fisher	>0.05
Total	Coastal Valley	268/496 891/1490	54.0 59.8	5.092	0.027	320/522 546/859	61.3 63.6	0.709	>0.05

Table 28: Chi-square test results of the association between enthesophytes and sex

Note: both right and left hand sides as well as all age categories were pooled. True prevalence rate is (n) the number of enthesophytes affected compared with (N) the number of enthesophytes available for study. Crude prevalence is (n) the number of individuals affected compared to (N) the number of individuals with entheses available for study. Chi-square analysis was performed on true prevalence values.

5.2.3 Enthesophytes according to age at death

The following section provides data on the presence of enthesophytes according to age by comparing true prevalence rates between coastal and inland groups.

Table 29 shows the Chi-square test results of the association between enthesophytes and age. Total true prevalence rates revealed significant differences between both groups only in the middle age category where coastal fishers were more affected than inland agriculturalists. When the comparison was divided up into separate entheseal areas, the early manifestations of enthesophytes were significantly higher at the elbow of coastal Chinchorro people. Towards middle adulthood, inland agriculturalists were more affected by enthesophytes at the knee than coastal fishers. No contrasting differences were observed between both groups in the old adult age category.

Tables 30- 31 show the results for the Kendall’s tau-b correlation between enthesophytes and age. Coastal and inland groups showed a progressive increase in the prevalence of enthesophytes with age at most entheseal areas. The only exception to this was the ankle of coastal fishers. The strength of the correlation varied from low ($r \geq 0.1$) to moderate ($r \geq 0.3$) in the majority of the enthesophytes analysed. The highest value of correlation was found at the hip in inland agriculturalists ($r=0.585$).

Site	Prev.	Coastal Y- A n/N	Inland Y- A n/N	x^2 (df=1)	p	Coastal M- A n/N	Inland M- A n/N	x^2 (df=1)	p	Coastal O- A n/N	Inland O- A n/N	x^2 (df=1)	p
Shoulder	True	36.2% (42/116)	36.9% (80/217)	0.014	>0.05	66.3% (57/90)	58.1% (158/270)	0.651	>0.05	63.6% (14/22)	70.7% (70/99)	0.424	>0.05
	Crude	65.5% (19/29)	86.1% (31/36)			83.3% (20/24)	93.6% (44/47)			83.3% (5/6)	100.0% (17/17)		
Elbow	True	44.6% (58/130)	31.9% (83/260)	6.048	0.019	55.6% (64/115)	49.40% (161/326)	1.336	>0.05	68.6% (24/35)	76.3% (103/135)	0.878	>0.05
	Crude	90.3% (28/31)	74.3% (26/35)			77.3% (17/22)	85.1% (40/47)			100.0% (8/8)	100.0% (17/17)		
Hip	True	64.3% (27/42)	50.0% (25/50)	1.896	>0.05	93.1% (27/29)	89.5% (60/67)	Fisher	>0.05	100.0% (9/9)	92.8% (26/28)	Fisher	>0.05
	Crude	64.0% (16/25)	50.0% (14/28)			94.4% (17/18)	94.4% (34/36)			100.0% (5/5)	100.0% (15/15)		
Knee	True	54.0% (127/235)	57.5% (160/278)	0.637	>0.05	70.2% (106/151)	80.5% (313/389)	6.591	0.012	73.0% (27/37)	87.6% (127/145)	Fisher	>0.05
	Crude	86.8% (33/38)	91.4% (32/35)			100.0% (25/25)	100.0% (47/47)			100.0% (8/8)	100.0% (17/17)		
Ankle	True	66.7% (2/3)	62.1% (18/29)	Fisher	>0.05	100.0% (3/3)	91.9% (34/37)	Fisher	>0.05	100.0% (1/1)	100.0% (19/19)	Fisher	>0.05
	Crude	50.0% (1/2)	64.7% (11/17)			100.0% (2/2)	91.7% (22/24)			100.0% (1/1)	100.0% (12/12)		
Total true prevalence		48.7% (256/526)	43.9% (366/834)	2.975	>0.05	71.1% (276/388)	66.7% (726/1089)	50.626	<0.001	72.1% (75/104)	81.0% (345/426)	3.999	>0.05

Table 29: Chi-square test results of the association between enthesophytes and age

Note: sexes and both right and left hand sides were pooled. True prevalence rate is the (n) number of enthesophytes affected according to the (N) number of enthesophytes available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals with entheses available for study. Chi-square analysis was performed on true prevalence values.

Entheseal area	Prev.	Coastal fishers Y- A n/N	M- A n/N	O- A n/N	Total n/N	r	p
Shoulder	True	36.2% (42/116)	57.8% (52/90)	63.6% (14/22)	47.3% (113/228)	0.354	0.001
	Crude	65.5% (19/29)	83.3% (20/24)	83.3% (5/6)	74.6% (44/59)		
Elbow	True	44.6% (58/130)	55.6% (64/115)	68.6% (24/35)	52.1% (146/280)	0.152	0.008
	Crude	90.3% (28/31)	77.3% (17/22)	100.0% (8/8)	86.9% (53/61)		
Hip	True	64.3% (27/42)	93.1% (27/29)	100.0% (9/9)	78.7% (63/80)	0.357	0.001
	Crude	64.0% (16/25)	94.4% (17/18)	100.0% (5/5)	79.2% (38/48)		
Knee	True	54.0% (127/235)	86.1% (130/151)	73.0% (27/37)	67.1% (260/423)	0.277	<0.001
	Crude	86.8% (33/38)	100.0% (25/25)	100.0% (8/8)	92.9% (66/71)		
Ankle	True	66.7% (2/3)	100.0% (3/3)	100.0% (1/1)	85.7% (6/7)	0.422	>0.05
	Crude	50.0% (1/2)	100.0% (2/2)	100.0% (1/1)	80% (4/5)		
Total true prevalence		48.7% (256/526)	71.1% (276/388)	72.1% (75/104)	59.6% (588/1018)	0.216	<0.001

Table 30: Kendall's tau_b correlation test between enthesophyte and age at death (Coastal group) Note: sexes and both right and left hand sides were pooled. True prevalence rate is the (n) number of enthesophytes affected compared to the (N) number of enthesophytes available for study. Crude prevalence is the (n) number of individuals affected (N) compared to the number of individuals with entheses available for study. The correlation was made considering true prevalence rates.

Entheseal area	Prev.	Inland agriculturalists				r	p
		Y- A n/N	M- A n/N	O- A n/N	Total n/N		
Shoulder	True	36.9% (80/217)	58.1% (158/270)	70.7% (70/99)	52.6% (308/586)	0.243	<0.001
	Crude	86.1% (31/36)	93.6% (44/47)	100.0% (17/17)	92.0% (92/100)		
Elbow	True	31.9% (83/260)	49.40% (161/326)	76.3% (103/135)	48.1% (347/721)	0.290	<0.001
	Crude	74.3% (26/35)	85.1% (40/47)	100.0% (17/17)	83.8% (83/99)		
Hip	True	50.0% (25/50)	89.5% (60/67)	92.8% (26/28)	76.5% (111/145)	0.585	<0.001
	Crude	50.0% (14/28)	94.4% (34/36)	100.0% (15/15)	79.7% (63/79)		
Knee	True	57.5% (160/278)	80.5% (313/389)	87.6% (127/145)	73.9% (600/812)	0.253	<0.001
	Crude	91.4% (32/35)	100.0% (47/47)	100.0% (17/17)	97.0% (96/99)		
Ankle	True	62.1% (18/29)	91.9% (34/37)	100.0% (19/19)	83.5% (71/85)	0.362	0.006
	Crude	64.7% (11/17)	91.7% (22/24)	100.0% (12/12)	84.9% (45/53)		
Total true prevalence		43.9% (366/834)	66.7% (726/1089)	81.0% (345/426)	61.1% (1437/2349)	0.269	<0.001

Table 31: Kendall‘s tau_b correlation test between enthesophyte and age at death (Inland group) Note: both sexes and right and left hand sides were pooled. True prevalence rate is the (n) number of enthesophytes affected compared to the (N) number of enthesophytes available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals with entheses available for study. The correlation was made considering true prevalence rates.

5.2.4 Enthesophytes and laterality

This section focuses on the analysis of enthesophytes according to side affected. Tables 32- 33 show the association between enthesophytes and laterality for both groups.

Site	Coastal fishers									
	Left				Right				x^2 (df=1)	p
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	48/100	48.0	34/51	66.7	65/128	50.8	37/55	67.3	0.174	>0.05
Elbow	60/127	47.2	35/49	71.4	86/153	56.2	43/52	82.7	2.235	>0.05
Hip	33/40	82.5	33/40	82.5	30/40	75.0	30/40	75.0	0.672	>0.05
Knee	120/201	59.7	56/66	84.8	140/222	63.1	59/68	86.8	0.503	>0.05
Ankle	2/2	100.0	2/2	100.0	4/5	80.0	4/5	80.0	Fisher	>0.05
Total	263/470	56.0	160/208	76.9	325/548	59.3	173/220	78.6	1.163	>0.05

Table 32: Chi-square test results of the association between enthesophytes and laterality (Coastal group)
Note: sex as well as all age categories was pooled. True prevalence rate is the (n) number of enthesophytes affected compared to the (N) number of enthesophytes available for study. Crude prevalence is the (n) number of individuals affected compared to the (N) number of individuals with entheses available for study. Chi-square was performed on true prevalence values.

The analysis of enthesophyte and laterality revealed a similar pattern of occurrence in both coastal and inland populations. No side dominance of enthesophyte was observed in any of the upper and lower limb entheseal areas. Chi-square analysis based on the total prevalence rates was also consistent with this trend among coastal X^2=1.163 (df =1) p>0.05 and inland groups X^2=0.290 (df =1) p>0.05.

Site	Inland agriculturalists									
	Left				Right				x^2 (df=1)	p
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	160/304	52.6	84/100	84.0	148/282	52.5	84/99	84.8	0.001	>0.05
Elbow	169/351	48.1	72/96	75.0	178/370	48.1	76/94	80.9	0.000	>0.05
Hip	53/70	75.7	53/70	75.7	58/75	77.3	58/75	77.3	0.053	>0.05
Knee	296/407	72.7	93/98	94.9	304/405	75.1	94/99	94.9	0.542	>0.05
Ankle	32/39	82.1	32/39	82.1	39/46	84.8	39/46	84.8	0.114	>0.05
Total	710/1171	60.6	334/403	82.9	727/1178	61.7	351/413	85.0	0.290	>0.05

Table 33: Chi-square test results of the association between enthesophytes and laterality (Inland group)
Note: sex as well as all age categories was pooled. True prevalence rate is the (n) number of enthesophytes affected compared to the (N) number of enthesophytes available for study. Crude prevalence is the (n) number of individuals affected compared to the (N) number of individuals with entheses available for study. Chi-square was performed on true prevalence values.

5.3 Osteoarthritis

The raw data on osteoarthritis for both populations can be found in Appendix 2.

The true prevalence rate for OA was 27.7% (682/2463) of joints affected in both coastal and inland groups. In the former group, 30.8% (282/916) of joints were affected by the condition. In the inland group, 25.9% (400/1547) of joints available for study were affected by the condition giving a coastal/inland frequency ratio of 1.2:1.

Crude prevalence rates, on the other hand, resulted in 54.3% (95/175) of individuals available with joints present for study. In the coastal group, 51.0% (38/75) of individuals with joints available for study were affected by OA, and in the inland group, 57.0% (57/100) of individuals with joints available for study were affected.

Examples of OA found in both skeletal populations are depicted in Figs 54 – 55

Figure 55: Az140 T105 showing absence of hyaline cartilage with porosity and osteoaphyte formation affecting the acromio-clavicular joint of the right shoulder

Figure 54: Mo1 T27 showing loss of hyaline cartilage on the joint margins of the glenoid cavity with underlying porosity of the subchondral bone of the right scapula (glenoid-humeral joint)

5.3.1 Osteoarthritis according to joint

Table 34 shows the prevalence rates obtained from the analysis of OA according to joint in both groups.

Joint	Coastal fishers				Inland agriculturalists				χ^2 (df=1)	p
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	51/157	32.5	26/58	44.8	85/344	24.7	47/97	48.4	3.295	>0.05
Elbow	123/316	38.9	30/65	46.1	162/556	29.1	42/99	42.4	8.773	0.003
Hip	46/124	37.1	27/69	39.1	65/187	34.8	41/98	41.8	0.177	>0.05
Knee	55/213	25.8	18/67	26.8	78/298	26.2	38/99	38.3	0.008	>0.05
Ankle	7/106	6.6	5/57	8.7	10/162	6.2	6/91	6.5	0.020	>0.05
Total	282/916	30.8	38/75	51.0	400/1547	25.9	57/100	57.0	6.983	0.009

Table 34: Prevalence rates of OA according to joint

Note: both right and left hand sides as well as all age categories were pooled. True: (n) number of joints affected (N) number of joints available for study, Crude: (n) number of individuals affected (N) number of individuals available with joints present for study. Chi-square was performed on true prevalence values.

Chi-square analysis revealed that the only significant difference in the distribution of OA between both groups was at the elbow joint. Coastal fishers were significantly more affected than inland agriculturalists. Chi-square analysis based on total true prevalence rates also revealed that coastal fishers were significantly more affected by the enthesophytes than inland agriculturalists X^2=6.983 (df =1) $p<0.05$.

5.3.2 Osteoarthritis according to sex

In this section, true and crude prevalence rates for OA were calculated intra-group and inter-group according to sex. Intra-group sex comparisons among coastal fishers (Tables 35 – 36) revealed no significant differences in any of the upper and lower limb joints analysed. Chi-square analysis based on total true prevalence rates also followed this trend.

Joint	Coastal fishers								X^2 (df=1)	p
	Female				Male					
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	28/76	36.8	14/28	50.0	23/81	28.4	12/30	40.0	1.276	>0.05
Elbow	54/147	36.7	14/31	45.2	69/169	40.8	16/34	47.1	0.554	>0.05
Hip	20/66	30.3	11/35	31.4	26/58	44.8	16/34	47.1	1.638	>0.05
Knee	28/113	24.8	9/34	26.5	27/100	27.0	9/33	27.3	0.137	>0.05
Ankle	6/61	9.8	4/32	12.5	1/45	2.2	1/25	4.0	Fisher	>0.05
Total	136/463	29.4	17/37	45.0	146/453	32.2	21/38	55.3	0.876	>0.05

Table 35: Prevalence rates of OA according to sex (Coastal group)

Note: both right and left hand sides as well as all age categories were pooled. True prevalence is the (n) number of joints affected compared to the (N) number of joints available for study. Crude prevalence is the (n) number of individuals affected compared to the (N) number of individuals with joints available for study. Chi-square was performed on true prevalence values.

Joint	Inland agriculturalists								X^2 (df=1)	p
	Female				Male					
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	55/215	25.6	30/61	49.2	30/129	23.3	17/36	47.2	0.234	>0.05
Elbow	94/341	27.6	25/62	40.3	68/215	31.6	17/37	45.9	1.054	>0.05
Hip	47/117	40.2	29/61	47.5	18/70	25.7	12/37	32.4	4.036	>0.05
Knee	55/186	29.6	27/62	43.5	23/112	20.5	11/37	29.7	2.963	>0.05
Ankle	7/108	6.5	4/58	6.9	3/54	5.6	2/33	6.1	Fisher	>0.05
Total	258/967	26.7	39/62	62.9	142/580	24.5	18/38	47.4	0.913	>0.05

Table 36: Prevalence rates of OA according to sex (Inland group)

Note: both right and left hand sides as well as all age categories were pooled. True prevalence rate is the (n) number of joints affected compared to the (N) number of joints available for study. Crude prevalence is the (n) number of individuals affected compared to the (N) number of individuals with joints available for study. Chi-square was performed on true prevalence values.

Inter-group sex comparison (Table 37) revealed that coastal and inland individuals from both sexes did not show statistical differences in the association between OA and sex, with the only exception being the hip where coastal males were more affected than inland males.

Sites		Female				Male			
		True n/N	%	χ^2 (df=1)	p	True n/N	%	χ^2 (df=1)	p
Shoulder	Coastal Valley	28/76 55/215	36.8 25.6	3.492	>0.05	23/81 30/129	28.4 23.3	0.696	>0.05
Elbow	Coastal Valley	54/147 94/341	36.7 27.6	4.087	>0.05	69/169 68/215	40.8 31.6	3.490	>0.05
Hip	Coastal Valley	20/66 47/117	30.3 40.2	1.771	>0.05	26/58 18/70	44.8 25.7	5.137	0.026
Knee	Coastal Valley	28/113 55/186	24.8 29.6	0.805	>0.05	27/100 23/112	27.0 20.5	1.225	>0.05
Ankle	Coastal Valley	6/61 7/108	9.8 6.5	0.618	>0.05	1/45 3/54	2.2 5.6	Fisher	>0.05
Total	Coastal Valley	136/463 258/967	29.4 26.7	0.876	>0.05	146/453 142/580	32.2 24.5	7.591	>0.05

Table 37: Chi-square test results of the association between OA and sex

Note: both right and left hand sides as well as all age categories were pooled. True prevalence is the (n) number of joints affected compared to the (N) number of joints available for study. Crude prevalence is the (n) number of individuals affected compared to the (N) number of individuals with joints available for study. Chi-square was performed on true prevalence values.

5.3.3 Osteoarthritis according to age at death

The following section analyses the presence of osteoarthritis according to age at death by comparing true prevalence rates of the coastal and inland groups. Following this, the results for the Kendall's tau-b correlation are presented separately for each group.

Table 38 shows the Chi-square test results for the association between OA and age. Total true prevalence rates revealed significant differences between both groups in all age categories. Coastal fishers were more affected than inland agriculturalists in the young and middle age group, although the inland agriculturalists were significantly more affected in the old adult group. When the comparison was divided into separate joints, the early manifestations of OA were significantly higher at the elbow and the hip of the coastal Chinchorro people. Towards middle adulthood, coastal fishers were more affected by OA at all joints with the exception of the ankle. No contrasting differences were observed between both groups in the old adult category.

Tables 39 and 40 show the results for the Kendall's tau-b correlation between OA and age. Coastal and inland groups showed a significant correlation of the condition with age with the only exception of the ankle joint of coastal fishers. A progressive increase in the prevalence of OA was evident across all age categories for inland agriculturalists at most joints. On the other hand, coastal fishers showed a progressive increase in OA from young to middle adulthood, with a decline in old adulthood, probably resulting from a marked reduction of individuals available for study in this age group. The strength of the correlation varied from low ($r \geq 0.1$) to moderate ($r \geq 0.3$) in the majority of the joints analysed. The highest value of correlation was found in the hip of the inland agriculturalists ($r=0.596$).

Joint	Prev.	Coastal Y- A n/N	Inland Y- A n/N	x^2 (df=1)	p	Coastal M- A n/N	Inland M- A n/N	x^2 (df=1)	p	Coastal O- A n/N	Inland O- A n/N	x^2 (df=1)	p
Shoulder	True	20.7% (17/82)	11.6% (14/121)	3.171	>0.05	51.7% (30/58)	24.7% (40/162)	14.387	<0.001	23.5% (4/17)	50.8% (31/61)	4.003	>0.05
	Crude	34.5% (10/29)	23.5% (8/34)			63.6% (14/22)	58.7% (27/46)			28.6% (2/7)	70.6% (12/17)		
Elbow	True	18.7% (29/155)	3.0% (6/199)	24.090	<0.001	58.9% (73/124)	38.4% (99/258)	14.217	<0.001	56.7% (21/37)	57.6% (57/99)	0.007	>0.05
	Crude	25.0% (8/32)	2.9% (1/35)			64.0% (16/25)	57.4% (27/47)			75.0% (6/8)	82.4% (14/17)		
Hip	True	14.5% (13/66)	4.5% (3/66)	7.112	0.014	64.4% (29/45)	40.9% (36/88)	6.600	0.011	30.8% (4/13)	78.8% (26/33)	Fisher	0.005
	Crude	21.6% (8/37)	5.7% (2/35)			66.7% (16/24)	54.3% (25/46)			37.5% (3/8)	82.4% (14/17)		
Knee	True	9.8% (11/112)	7.0% (7/100)	0.541	>0.05	40.8% (31/76)	26.8% (37/138)	4.417	0.046	52.0% (13/25)	56.7% (34/60)	0.155	>0.05
	Crude	8.1% (3/37)	17.1% (6/35)			45.5% (10/22)	38.3% (18/47)			62.5% (5/8)	82.4% (14/17)		
Ankle	True	1.7% (1/59)	0.0% (0/58)	Fisher	>0.05	6.2% (10/162)	4.0% (3/74)	0.438	>0.05	7.1% (1/14)	23.3% (7/30)	Fisher	>0.05
	Crude	3.2% (1/31)	0.0% (0/32)			16.7% (3/18)	4.7% (2/43)			12.5% (1/8)	25.0% (4/16)		
Total true prevalence		15.0% (71/474)	5.5% (30/544)	25.386	<0.001	50.0% (168/336)	29.9% (215/720)	40.197	<0.001	40.6% (43/106)	54.8% (155/283)	6.226	0.017

Table 38: Chi-square test results of the association between OA and age

Note: sexes and both right and left hand sides were pooled. True: (n) number of joints affected (N) number of joints available for study. Crude prevalence (n) number of individuals affected (N) number of individuals with joints available for study. Chi-square was performed on true prevalence values.

Joint	Prev.	Coastal fishers Y- A n/N	M- A n/N	O- A n/N	Total n/N	r	p
Shoulder	True	20.7% (17/82)	51.7% (30/58)	23.5% (4/17)	32.5% (51/157)	0.203	0.009
	Crude	34.5% (10/29)	63.6% (14/22)	28.6% (2/7)	44.8% (26/58)		
Elbow	True	18.7% (29/155)	58.9% (73/124)	56.7% (21/37)	38.9% (123/316)	0.370	<0.001
	Crude	25.0% (8/32)	64.0% (16/25)	75.0% (6/8)	46.1% (30/65)		
Hip	True	14.5% (13/66)	64.4% (29/45)	30.8% (4/13)	37.1% (46/124)	0.308	<0.001
	Crude	21.6% (8/37)	66.7% (16/24)	37.5% (3/8)	39.1% (27/69)		
Knee	True	9.8% (11/112)	40.8% (31/76)	52.0% (13/25)	25.8% (55/213)	0.553	<0.001
	Crude	8.1% (3/37)	45.5% (10/22)	62.5% (5/8)	26.9% (18/67)		
Ankle	True	1.7% (1/59)	15.1% (5/33)	7.1% (1/14)	6.6% (7/106)	0.128	>0.05
	Crude	3.2% (1/31)	16.7% (3/18)	12.5% (1/8)	8.8% (5/57)		
Total true prevalence		15.0% (71/474)	50.0% (168/336)	40.6% (43/106)	30.8% (282/916)	0.312	<0.001

Table 39: Kendall‘s tau_b correlation test between OA and age at death (Coastal group)
Note: sexes and both right and left hand sides were pooled. True prevalence is the (n) number of joints affected compared to the (N) number of joints available for study. Crude prevalence is the (n) number of individuals affected compared to the (N) number of individuals with joints available for study. The correlation was made considering true prevalence rates.

Joint	Prev.	Inland agriculturalists				r	p
		Y- A n/N	M- A n/N	O- A n/N	Total n/N		
Shoulder	True	11.6% (14/121)	24.7% (40/162)	50.8% (31/61)	24.7% (85/344)	0.283	<0.001
	Crude	23.5% (8/34)	58.7% (27/46)	17.6% (3/17)	39.3% (38/97)		
Elbow	True	3.0% (6/199)	38.4% (99/258)	57.6% (57/99)	29.1% (162/556)	0.422	<0.001
	Crude	2.9% (1/35)	57.4% (27/47)	82.3% (14/17)	42.4% (42/99)		
Hip	True	4.5% (3/66)	40.9% (36/88)	78.8% (26/33)	34.8% (65/187)	0.596	<0.001
	Crude	5.7% (2/35)	54.3% (25/46)	82.3% (14/17)	41.8% (41/98)		
Knee	True	7.0% (7/100)	26.8% (37/138)	56.7% (34/60)	26.2% (78/298)	0.384	<0.001
	Crude	14.3% (5/35)	38.3% (18/47)	82.3% (14/17)	37.4% (37/99)		
Ankle	True	0.0% (0/58)	4.0% (3/74)	23.3% (7/30)	6.2% (10/162)	0.308	<0.001
	Crude	0.0% (0/32)	4.6% (2/43)	31.2% (5/16)	11.9% (7/59)		
Total true prevalence		5.5% (30/544)	29.9% (215/720)	54.8% (155/283)	25.9% (400/1547)	0.379	<0.001

Table 40: Kendall‘s tau_b correlation test between OA and age at death (Inland group)
Note: sexes and both right and left hand sides were pooled. True prevalence rate is the (n) number of joints affected compared to the (N) number of joints available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals with joints available for study. The correlation was made considering true prevalence rates.

5.3.4 Osteoarthritis and laterality

This section focuses on the analysis of OA according to side. Tables 41 and 42 show the association between OA and laterality for both groups.

The analysis of OA and laterality revealed a similar pattern for both coastal and inland populations. No side dominance of the condition was observed in any of the upper and lower limbs joints. Chi-square analysis based on total true prevalence rates was also consistent with this trend among coastal X^2=0.024 (df =1) p>0.05 and inland groups X^2=0.132 (df =1) p>0.05.

Joint	Coastal fishers									
	Left				Right				χ^2 (df=1)	p
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	28/76	36.8	21/48	43.8	23/81	28.4	18/51	35.3	1.276	>0.05
Elbow	57/149	38.3	24/55	43.6	66/167	39.5	27/61	44.3	0.053	>0.05
Hip	23/67	34.3	23/67	34.3	23/57	40.4	23/57	40.4	0.479	>0.05
Knee	27/103	26.2	18/62	29.0	28/110	25.5	18/66	27.3	0.016	>0.05
Ankle	4/53	7.5	4/53	7.5	3/53	5.7	3/53	5.7	0.153	>0.05
Total	139/448	31.0	90/285	31.6	143/468	30.6	89/288	30.9	0.024	>0.05

Table 41: Chi-square test results of the association between OA and laterality (Coastal group)

Note: sex as well as all age categories was pooled. True prevalence rate is the (n) number of joints affected compared to the (N) number of joints available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals with joints available for study. Chi-square was performed on true prevalence values.

Joint	Inland agriculturalists									
	Left				Right				χ^2 (df=1)	p
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Shoulder	41/177	23.2	36/94	38.3	44/167	26.3	37/93	39.8	0.468	>0.05
Elbow	77/278	27.7	35/95	36.8	85/278	30.6	37/96	38.5	0.557	>0.05
Hip	33/92	35.9	33/92	35.9	32/95	33.7	32/95	33.7	0.098	>0.05
Knee	40/151	26.5	31/97	32.0	38/147	25.9	28/97	28.9	0.016	>0.05
Ankle	6/76	7.9	6/76	7.9	4/86	4.7	4/86	4.7	0.733	>0.05
Total	197/774	25.5	141/454	31.1	203/773	35.6	138/467	30.0	0.132	>0.05

Table 42: Chi-square test results of the association between OA and laterality (Inland group)

Note: sex as well as all age categories was pooled. True prevalence rate is the (n) number of joints affected compared to the (N) number of joints available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals with joints available for study. Chi-square was performed on true prevalence values.

5.4 Spondylolysis

The true prevalence rate for spondylolysis was 2.3% (16/682) of lumbar vertebrae for both coastal and inland groups. In the former group, 4.0% (11/271) of vertebrae were affected by the condition, and in the inland group 1.2% (5/411) of vertebrae available for study were affected, giving a coastal/inland ratio rate of a little more than 3:1.

Crude prevalence rates, on the other hand, resulted in 10.2% (15/147) of individuals affected with at least one lumbar vertebra present for study. In the coastal group, 16.4% (10/61) of individuals with at least one lumbar vertebra available for study were affected and for the inland group, 5.8% (5/86) of individuals were affected.

5.4.1 Spondylolysis according to vertebra

Table 43 shows true prevalence rates for spondylolysis according to vertebra affected in both groups. Further detailed information on the particular individuals affected by spondylolysis can be found in Table 44.

Vertebra	Coastal fishers		Inland agriculturalists		Total	%
	True n/N	%	True n/N	%		
L1	0/56	0.0	0/82	0.0	0/138	0.0
L2	0/58	0.0	0/82	0.0	0/140	0.0
L3	0/53	0.0	0/83	0.0	0/136	0.0
L4	1/47	2.1	0/81	0.0	1/128	0.7
L5	10/54	18.5	5/82	6.0	15/136	11.1
L6	0/3	0.0	0/1	0.0	0/4	0.0
Total	11/271	4.0	5/411	1.2	16/682	2.3

Table 43: Prevalence rates of spondylolysis according to vertebra
Note: sex as well as all age categories was pooled. True prevalence is the (n) number of vertebrae affected compared to the (N) number of vertebrae available for study.

The fifth lumbar was the most common vertebra affected by spondylolysis in both populations. From a total of 16 cases of spondylolysis, 15 (11.1%) occurred in L5 and one (0.7%) in L4, with no evidence in the remainder lumbar vertebrae. Chi-square analysis based on these total true prevalence rates revealed that spondylolysis was significantly more prevalent in the coastal group than in the inland agriculturalists $X^2=5.760$ (df=1) $p<0.020$

Groups	Sites	Individual	Sex	Age	Vertebra
Coastal Fishers	Morro 1	Tomb 10A	M	Y-A	L5
		Tomb 27 C-4	M	Y-A	L5
		Tomb 27 C-5	M	Y-A	L5
		Tomb 28 C-11	M	Y-A	L4-L5
	Morro 1/6	Tomb 9	M	O-A	L5
		Tomb 18	M	M-A	L5
		Tomb 21	M	M-A	L5
		Tomb 41	M	O-A	L5
		Tomb 50	M	Y-A	L5
		Tomb 53	F	Y-A	L5
Inland agriculturalists	Az 71	Tomb 601	M	O-A	L5
		Tomb 605	F	O-A	L5
	Az 140	Tomb 39	F	Y-A	L5
	Az 141	Tomb 49	F	Y-A	L5
		Tomb 53	M	Y-A	L5

Table 44: Information on individuals affected by spondylolysis

One individual was found to be affected by spondylolysis in multiple vertebrae. This unique case was a coastal male (Mo1Tomb28C11) who had two contiguous vertebrae, L4 and L5, involved (Fig 56). The remaining cases exhibited the condition in only one vertebra (L5).

Figure 56: Mo1 T28C11 showing L1 to L5 (left) and spondylolysis at L4 and L5 (right)

5.4.2 Spondylolysis according to sex

Prevalence rate comparisons between the sexes for both coastal and inland populations were carried out according to the vertebra affected (Tables 45 - 46). Inter-group sex comparisons between coastal males and females based on total true prevalence rates revealed that the former group was significantly more affected by spondylolysis than the females (X^2=8.173 (df =1) 0.004 $p<0.05$). Inter-group sex comparisons between inland males and females based on total true prevalence rates showed an equal distribution of the condition between the sexes. It was not possible to use Chi-square analysis due to low expected counts; however, the Fisher's exact test showed, as expected, no significant differences between these prevalence rates (Fisher's exact= 1.000 (df=1) $p>0.05$).

Vertebra	Coastal fishers							
	Female				Male			
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%
L1	0/28	0.0	0/28	0.0	0/28	0.0	0/28	0.0
L2	0/29	0.0	0/29	0.0	0/29	0.0	0/29	0.0
L3	0/27	0.0	0/27	0.0	0/26	0.0	0/26	0.0
L4	0/26	0.0	0/26	0.0	1/21	4.8	1/21	4.8
L5	1/27	3.7	1/27	3.7	9/27	33.3	9/27	33.3
L6	0/2	0.0	0/2	0.0	0/1	0.0	0/1	0.0
Total	1/139	0.7	1/30	3.3	10/132	7.6	9/31	29

Table 45: Prevalence rates of spondylolysis according to sex (Coastal group) Note: all age categories were pooled. True prevalence rate is the (n) number of vertebrae affected compared to the (N) number of vertebrae available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals available with at least one lumbar vertebra present for study.

Vertebra	Inland agriculturalists							
	Female				Male			
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%
L1	0/48	0.0	0/48	0.0	0/34	0.0	0/34	0.0
L2	0/49	0.0	0/49	0.0	0/33	0.0	0/33	0.0
L3	0/49	0.0	0/49	0.0	0/34	0.0	0/34	0.0
L4	0/50	0.0	0/50	0.0	0/31	0.0	0/31	0.0
L5	3/50	6.0	3/50	6.0	2/32	6.2	2/32	6.2
L6	0/0	0.0	0/0	0.0	0/1	0.0	0/1	0.0
Total	3/246	1.2	3/52	5.8	2/165	1.2	2/34	5.9

Table 46: Prevalence rates of spondylolysis according to sex (Inland group) Note: all age categories were pooled. True prevalence rate is the (n) number of vertebrae affected compared to the (N) number of vertebrae available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals available with at least one lumbar vertebra present for study.

Inter-group sex comparisons performed between males of both groups based on total true prevalence rates revealed that coastal Chinchorro were significantly more affected by spondylolysis than inland agriculturalists (X^2=7.659 (df=1) 0.005 $p<0.05$).

Comparisons between females were not possible to assess with Chi-square analysis as expected counts were smaller than five. The alternative Fisher's exact test revealed no significant differences between both groups (Fisher's exact= 1.000 (df=1) p>0.05). To summarise, coastal fishers showed more intra-group variation compared to inland agriculturalists. Chinchorro males were significantly more affected by spondylolysis compared to the females and to their inland counterparts in a ratio of approximately 5:1.

5.4.3 Spondylolysis according to age at death

The following section analyses the presence of spondylolysis at the intra-group level for both coastal and inland groups according to age at death. Statistical analysis aiming to compare these age-related prevalence rates was not possible because the samples were too small. On the other hand, Tables 47 - 48 show that spondylolysis affected all age groups in both coastal and inland groups. On the basis of total true prevalence rates, there appears to be no progression of the condition with age.

Sex	Coastal females					Coastal females			
Age	Y- A	M- A	O- A	Total		Y- A	M- A	O- A	Total
True prevalence	1.5% 1/67	0.0% 0/54	0.0% 0/18	0.7% 1/139	Crude prevalence	6.7% 1/15	0.0% 0/11	0.0% 0/4	3.3% 1/30
	Coastal males					Coastal males			
	8.2% 6/73	4.4% 2/45	14.3% 2/14	7.6% 10/132		29.4% 5/17	18.2% 2/11	66.7% 2/3	29.0% 9/31
Total	5.0% 7/140	2.0% 2/99	6.2% 2/32	4.0% 11/271		18.8% 6/32	9.1% 2/22	28.6% 2/7	16.3% 10/61

Table 47: Prevalence rates of spondylolysis according to age (Coastal group)

Note: True prevalence rate is the (n) number of vertebrae affected compared to the (N) number of vertebrae available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals available with at least one lumbar vertebra present for study.

Sex	Inland females					Inland females			
Age	Y- A	M- A	O- A	Total		Y- A	M- A	O- A	Total
True Prevalence	2.2% 2/93	0.0% 0/98	1.8% 1/55	1.2% 3/246	Crude prevalence	10.5% 2/19	0.0% 0/21	8.3% 1/12	5.8% 3/52
	Inland males					Inland males			
	1.9% 1/54	0.0% 0/96	6.7% 1/15	1.2% 2/165		9.1% 1/11	0.0% 0/20	33.3% 1/3	5.9% 2/34
Total	2.0% 3/147	0.0% 0/194	2.8% 2/70	1.2% 5/411		10% 3/30	0.0% 0/41	13.3% 2/15	5.8% 5/86

Table 48: Prevalence rates of spondylolysis according to age (Inland group)

Note: True prevalence rate is the (n) number of vertebrae affected compared to the (N) number of vertebrae available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals available with at least one lumbar vertebra present for study.

5.5 Os acromiale

The true prevalence rate for os acromiale was 4.8% (12/251) of acromia for both coastal and inland groups. In the former group 5.8% (5/86) of acromia available for study were affected, four right acromia and one left. In the inland group 4.2% (7/165) of acromia available for study were affected, four right acromia and three left, giving a coastal/inland ratio rate of 1.4:1.

Crude prevalence rates, on the other hand, showed that 6.3% (9/142) of individuals with at least one acromion available for study were affected by os acromiale. In the coastal group, 7.7% (4/52) of individuals with at least one acromion present for study were, two bilaterally and one unilaterally (right side), and the last individual was affected unilaterally (right side) but the left acromion was unavailable for observation. In the inland group, 5.5% (5/90) of individuals with at least one acromion present for study were affected, two bilaterally and three unilaterally, giving again a slightly higher prevalence of the condition in the coastal group.

5.5.1 Os acromiale according to acromion

This section focuses on the analysis of os acromiale according to acromion and also provides information on the pattern of the condition according to laterality. Table 49 shows true prevalence rates of os acromiale according to acromion in both groups.

Acromia	Coastal fishers				Inland agriculturalists				Total True n/N	%
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Right	4/43	9.3	4/43	9.3	4/83	4.8	4/83	4.8	8/126	6.3
Left	1/43	2.3	1/43	2.3	3/82	3.6	3/82	3.6	4/125	3.2
Total	5/86	5.8	4/52	7.7	7/165	4.2	5/90	5.6	12/251	4.8

Table 49: Prevalence rates of os acromiale according to acromion

Note: sex as well as all age categories was pooled. True prevalence rate is the (n) number of acromia affected compared to the (N) number of acromia available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals available with at least one acromion present for study.

Inter-group comparisons performed on the basis of total true prevalence rates indicated that coastal fishers were more affected than inland agriculturalists, although this comparison was not statistically significant (Fisher's exact= 0.551 (df=1) p>0.05).

Inter-group comparisons between same side acromia revealed no significant difference between right acromia of coastal fishers and inland agriculturalists (Fisher's exact= 0.443 (df=1) p>0.05). A similar result was found when the comparison involved the left acromia of both groups (Fisher's exact= 1.000 (df=1) p>0.05).

Intra-group comparisons revealed that there was no difference between right and left acromia of coastal fishers (Fisher's exact= 0.360 (df=1) p>0.05) and a similar pattern was observed between right and left acromia of inland agriculturalists (Fisher's exact= 1.000 (df=1) p>0.05).

Further detailed information on the particular individuals affected by this condition can be found in Table 50.

	Site	Individual	Sex	Age	Right	Left
Coastal Fishers	Morro1	Tomb 19 C-1	M	Y-A	Yes	No
		Tomb 27 C-4	M	Y-A	Yes	No
		Tomb 27 C-12	M	M-A	Yes	Unavailable
		Tomb 28 C-7	M	M-A	Yes	Yes
Inland agriculturalists	Az140	Tomb 16	M	M-A	Yes	Yes
		Tomb 75	M	M-A	Yes	No
		Tomb 100	F	M-A	No	Yes
		Tomb XPB	F	Y-A	Yes	Yes
	Az141	Tomb desc 02	F	M-A	Yes	No

Table 50: Information on individuals affected by os acromiale

Os acromiale was bilateral in one case within the coastal group, and was found present unilaterally in at least three cases. Within the inland agriculturalists, os acromiale was found to be bilateral in two cases and unilateral in three cases. Examples of bilateral and unilateral os acromiale are shown in Figs 57 and 58.

In summary, when the information from both groups was pooled, unilateral os acromiale occurred in six examples whereas bilateral involvement occurred in three cases, giving a unilateral/bilateral rate ratio of 1:2. Unilateral involvement occurred in one individual affecting the left acromion only, compared to five cases affecting the right acromion only, giving a right/left ratio of 5:1.

Figure 57: Az140 TXPB showing bilateral os acromiale

Figure 58: Az140 T100 showing os acromiale affecting the left acromion

5.5.2 Os acromiale according to sex

Prevalence comparisons between the sexes from both coastal and inland populations were carried out according to the acromia affected (Tables 51 and 52).

Acromia	Coastal fishers							
	Female				Male			
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%
Right	0/22	0.0	0/26	0.0	4/21	19.0	4/26	15.4
Left	0/21	0.0			1/22	4.5		
Total	0/43	0.0	0/26	0.0	5/43	11.6	4/26	15.4

Table 51: Prevalence rates of os acromiale according to sex (Coastal group) Note: all age categories were pooled. True prevalence rate is the (n) number of acromia affected compared to the (N) number of acromia available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals available with at least one acromion present for study.

Acromia	Inland agriculturalists							
	Female				Male			
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%
Right	2/53	3.8	3/56	5.4	2/30	6.7	2/34	5.9
Left	2/53	3.8			1/29	3.4		
Total	4/106	3.8	3/56	5.4	3/59	5.1	2/34	5.9

Table 52: Prevalence rates of os acromiale according to sex (Inland group) Note: all age categories were pooled. True prevalence rat is the (n) number of acromia affected compared to the (N) number of acromia available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals available with at least one acromion present for study.

It was not possible to perform Chi-square analysis to assess intra-group sex differences among coastal fishers because the females did not present any example of the condition. Comparisons among inland agriculturalists showed fairly equal prevalence rates for os acromiale. It was not possible to calculate Chi-square analysis due to low expected counts, but the Fisher's exact test showed, as expected, no significant differences between these prevalence rates (Fisher's exact= 0.701 (df=1) $p>0.05$).

Chi-square analysis of differences between the groups by sex was not possible because of low expected counts, but the alternative Fisher's exact test revealed no significant differences between males (Fisher's exact= 0.277 (df=1) $p>0.05$). It was not possible to compare frequencies between females with either test because the female coastal group did not exhibit any evidence of os acromiale.

5.5.3 Os acromiale according to age at death

The following section analyses the presence of os acromiale between coastal and inland groups. Statistical analysis aimed at comparing these age-related prevalence rates was not possible because the samples were too small. On the other hand, Tables 53 - 54 show that os acromiale affected all but old adult individuals for both groups. On the basis of total true prevalence rate observation, there appears to be an increase in os acromiale from young to middle adult age.

	Coastal females					Coastal females			
Age	Y-A	M-A	O-A	Total		Y-A	M-A	O-A	Total
True Prevalence	0.0% 0/26	0.0% 0/13	0.0% 0/4	0.0% 0/43	Crude prevalence	0.0% 0/15	0.0% 0/9	0.0% 0/2	0.0% 0/26
	Coastal males					Coastal males			
	8.7% 2/23	18.8% 3/16	0.0% 0/4	11.6% 5/43		15.4% 2/13	18.2% 2/11	0.0% 0/2	15.4% 4/26
Total	4.1% 2/49	10.% 3/29	0.0% 0/8	5.8% 5/86		7.1% 2/28	10.0% 2/20	0.0% 0/4	7.7% 4/52

Table 53: Prevalence rates of os acromiale according to age at death (Coastal group)
Note: True prevalence rate is the (n) number of acromia affected compared to the (N) number of acromia available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals available with at least one acromion present for study.

	Inland females					Inland females			
Age	Y-A	M-A	O-A	Total		Y-A	M-A	O-A	Total
True prevalence	5.4% 2/37	4.4% 2/45	0.0% 0/24	3.8% 4/106	Crude Prevalence	5.0% 1/20	8.7% 2/23	0.0% 0/13	5.3% 3/56
	Inland males					Inland males			
	0.0% 0/20	9.1% 3/33	0.0% 0/6	5.1% 3/59		0.0% 0/11	10.0% 2/20	0.0% 0/3	5.9% 2/34
Total	3.5% 2/57	6.4% 5/78	0.0% 0/30	4.2% 7/165		3.2% 1/31	9.3% 4/43	0.0% 0/16	5.5% 5/90

Table 54: Prevalence rates of os acromiale according to age at death (Inland group)

Note: True prevalence rat is the (n) number of acromia affected according to (N) number of acromia available for study. Crude prevalence rate is the (n) number of individuals affected according to (N) number of individuals available with at least one acromion present for study.

5.6 Osteochondritis dissecans

The true prevalence rate for osteochondritis dissecans was 0.6% (2/314) of knee joints in both coastal and inland groups. These skeletal changes were present bilaterally in the knee joints of the same individual. The crude prevalence rate, on the other hand, was 0.6% (1/175) of individuals with at least one knee joint available for study.

Table 55 shows true and crude prevalence rates for both coastal and inland populations.

Knee Joint	Coastal fishers				Inland agriculturalists				Total	%
	True n/N	%	Crude n/N	%	True n/N	%	Crude n/N	%		
Right	1/62	1.6	1/67	1.5	0/95	0.0	0/99	0.0	1/157	0.6
Left	1/60	1.7			0/97	0.0			1/157	0.6
Total	2/122	1.6	1/67	1.5	0/192	0.0	0/99	0.0	2/314	0.6

Table 55: Prevalence rates of osteochondritis dissecans according to joint

Note: sex as well as all age categories were pooled. True prevalence rate is the (n) number of knees affected compared to the (N) number of knee available for study. Crude prevalence rate is the (n) number of individuals affected compared to the (N) number of individuals with knee joints available for study. The knee joint represents the information retrieved from the femoro-tibial joint.

The individual affected by osteochondritis dissecans was a middle adult female coastal Chinchorro (Morro1/5 Tomb TXVII) who was affected bilaterally on both femoral condyles. The right medial femoral trochlear facet exhibited a circular crater-like depression of nine mm in diameter and five mm in depth located on the anterior articular surface (Fig 59). The left medial femoral trochlear facet demonstrated a similar lesion with a slightly more irregular geometry (Fig 60).

Figure 60: Mo1/5 TXVII showing the crater on the right medial femoral condyle

Figure 59: Mo1/5 TXVII showing the crater on the left medial femoral condyle

Interestingly, three loose bodies which appeared to have originated from these lesions were recovered (Fig 61). One of them, the right loose body, showed a smooth and even contour to the anterior face but the posterior face showed a scar, which could have resulted from the detachment (Fig 62). This loose body had a fairly circular shape and outline that probably resulted from rolling free inside the joint space, suggesting that the condition developed years before death. The other two loose bodies of the left knee were slightly more asymmetric and had small spicules of bone, suggesting a more recent development (Fig 61). Figures 63 and 64 show both femoral condyles with the loose bodies repositioned. As no other individuals were present with osteochondritis dissecans, no further statistical comparison was performed.

Figure 62: Mo1/5 TXVII showing three loose bodies that originated from both femoral condyles

Figure 61: Mo1/5 TXVII showing anterior and posterior view of loose body recovered from the right femoral condyle

Figure 64: Mo1/5 TXVII showing right femoral condyle with loose body repositioned

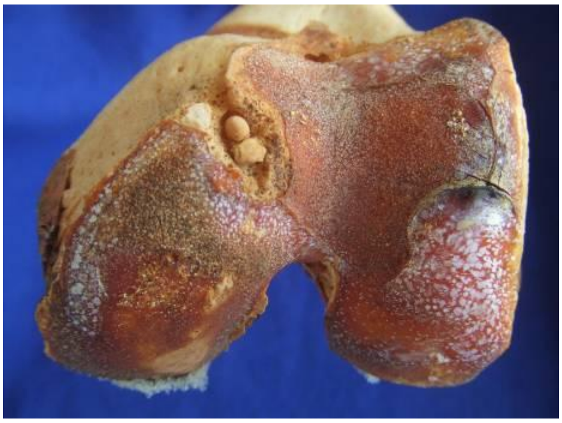


Figure 63: Mo1/5 TXVII showing left femoral condyle with loose bodies repositioned

5.7 Osteometric analysis

A total of 243 humeri (123 right and 120 left), 285 femora (136 right and 149 left) and 293 tibiae (149 right and 144 left) were available for study. From this total, 77 humeri belonged to the coastal sample (42 right and 35 left) and 165 belonged to the inland group (81 right and 84 left). Similarly, 110 femora were available from the coastal group (52 right and 58 left) and 175 belonged to the inland group (84 right and 91 left). Available tibiae from the coastal group were 112 (58 right and 54 left), and 181 from the inland group (91 right and 90 left).

5.7.1 Osteometric analysis according to index

Intra-group analysis of dependent means t-test was calculated for humeral robusticity (HR), tibial robusticity (TR), femoral platymeric (HP) and tibial platycnemic (TP) indices and is shown in Table 56.

Index		Coastal fishers							
		n	Min	Max	Mean	Sd	t-test	df	p
Humerus Robusticity	Right	42	17.6	23.4	20.5	1.4	2.671	27	0.013
	Left	35	17.7	23.3	19.9	1.3			
		Inland agriculturalists							
	Right	81	17.1	24.2	20.0	1.2	Wilcoxon -1.032		>0.05
	Left	84	17.8	23.4	20.0	1.2			
Femur Robusticity		Coastal fishers							
	Right	52	10.3	14.3	12.1	0.7	-2.066	42	0.045
	Left	58	10.8	14.4	12.2	0.7			
		Inland agriculturalists							
	Right	84	10.6	13.5	12.0	0.7	-0.162	78	>0.05
	Left	91	10.1	13.3	12.0	0.6			
Femur Platymeric		Coastal fishers							
	Right	56	64.5	96.2	78.3	6.2	-1.932	50	>0.05
	Left	63	69.0	96.4	80.9	6.7			
		Inland agriculturalists							
	Right	96	67.7	109.1	81.8	7.5	-2.654	93	0.009
	Left	96	63.6	103.5	83.8	6.6			
Tibia Platycnemic		Coastal fishers							
	Right	58	62.1	84.6	70.4	5.0	Wilcoxon -0.628		>0.05
	Left	54	58.6	80.0	68.1	4.8			
		Inland agriculturalists							
	Right	91	48.7	93.3	68.2	7.0	0.845	84	>0.05
	Left	90	52.8	93.3	67.6	6.4			

Table 56: Paired means t-test comparing laterality intra group

Note: (n) is the number of cases; Min is the minimum value; Max is the maximum value; Sd is the standard deviation; df is the degrees of freedom. Both sexes and all ages were pooled. Wilcoxon signed-rank test calculated when the paired t-test was not possible to calculate due to a non-normal distribution.

Intra-group t-test comparisons of laterality revealed that the right humeri of coastal individuals were significantly more robust than the left. However, no side robusticity dominance was observed among the inland agriculturalists. A similar pattern was observed with regard to femoral robusticity although, in this case, the left femora appeared to be significantly more robust in coastal fishers, with no side dominance in the inland group. T-test comparisons for the platymeric index revealed significant side differences among inland agriculturalists and non-significant side dominance for coastal Chinchorros. The platycnemic index showed no significant asymmetries for both groups.

Inter-group analysis of independent means t-test calculated for humeral robusticity (HR), tibial robusticity (TR), femoral platymeric (HP) and tibial platycnemic (TP) indices and is shown in Table 57.

Index		Coastal fishers					Inland agriculturalists					t-test	df	p
		n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd			
HR	R	42	17.6	23.4	20.5	1.4	81	17.1	24.2	20.0	1.2	1.948	121	>0.05
	L	35	17.7	23.3	19.9	1.3	84	17.8	23.4	20.0	1.2	Mann-Whitney 1.402		>0.05
	R+L	77	17.6	23.4	20.2	1.4	165	17.1	24.2	20.0	1.2	Mann-Whitney 5.788		>0.05
FR	R	52	10.3	14.3	12.1	0.7	84	10.6	13.5	12.0	0.7	0.916	134	>0.05
	L	58	10.8	14.4	12.2	0.7	91	10.1	13.3	12.0	0.6	2.066	147	0.041
	R+L	110	10.3	14.4	12.2	0.7	175	10.1	13.5	12.0	0.6	Mann-Whitney 8.508		>0.05
FP	R	56	64.5	96.2	78.3	6.2	96	67.7	109.1	81.8	7.5	-2.914	150	0.004
	L	63	69.0	96.4	80.9	6.7	96	63.6	103.5	83.8	6.6	-2.699	157	0.008
	R+L	119	64.5	96.4	79.7	6.5	192	63.6	109.1	82.8	7.1	-3.932	309	<0.001
TP	R	58	62.1	84.6	70.4	5.0	91	48.7	93.3	68.2	7.0	Mann-Whitney 2124.000		0.045
	L	54	58.6	80.0	68.1	4.8	90	52.8	93.3	67.6	6.4	0.473	142	>0.05
	R+L	112	58.6	84.6	69.3	5.0	181	48.7	93.3	67.9	6.7	Mann-Whitney 8.884		>0.05

Table 57: Independent means t-test comparing laterality inter group

Note: (n) is the number of cases; Min is the minimum value; Max is the maximum value; Sd is the standard deviation; df is the degrees of freedom. Both sexes and all ages were pooled. Mann Whitney statistical test calculated when the independent t-test was not possible to be calculated due to a non-normal distribution.

Inter-group comparisons revealed that the only statistically significant comparison between both groups was found at the femoral platymeric index. According to Bass (2005), both femora (R+L) of coastal and inland populations were platymeric or flattened antero-posteriorly in the region of the proximal shaft (values ≥ 84.9).

5.7.2 Osteometric analysis according to sex

In this section, intra-group and inter-group comparisons are presented according to sex. Tables 58 - 59 show the results for the independent means t-test analysis comparing intra-group laterality for the four indices analysed.

Intra-group comparisons among the coastal Chinchorro (Table 58) revealed no side difference in femoral robusticity, or the platymeric and platycnemic indices between the sexes. The only side dominance was found in the humeral robusticity index. Chinchorro males appeared to be predominantly more robust in their right arms compared with the females.

Intra-group comparisons among inland agriculturalists (Table 59) revealed that with the only exception of the tibial platicnemic index, the remaining indices showed statistically significant results between the sexes. Inland males exhibited more robust arms and legs than the females. Similarly, statistically significant differences were also found at the femoral platymeric index. The mean values for both (R+L) femora showed that both sexes were platymeric or flattened antero-posteriorly in the region of the proximal shaft (values $\geq$ 84.9). A higher mean value among males (84.2) compared with that of the females (82.0) meant that the former group was less mechanically stressed than the latter.

The results for the independent means t-test analysis comparing inter-site laterality for the four indices analysed are presented in Tables 60 - 61.

Comparisons of mean humeral robusticity indices between coastal and inland females were not significant (Table 60). However, the differences were significant when comparison involved femoral robusticity, where coastal females showed a higher degree of hypertrophy. In line with this result, coastal females appeared to be more mechanically stressed according to the results of the femoral platymeric index.
Data from the tibial platycnemic index showed that only the right tibiae of the inland females showed more signs of mechanical stress than the Chinchorro females.

Coastal fishers												t-test	df	p
Index		Females					Males							
		n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd			
HR	R	21	17.6	22.1	20.0	1.2	21	18.9	23.4	21.0	1.4	-2.327	40	0.025
	L	16	17.8	22.6	19.7	1.3	19	18.2	23.3	20.1	1.4	Mann-Whitney 119.000		>0.05
	R+L	37	17.6	22.6	19.9	1.2	40	18.2	23.4	20.5	1.4	-2.169	75	0.033
FR	R	32	11.1	13.3	12.1	0.5	20	10.3	14.3	12.1	0.9	0.045	50	>0.05
	L	28	10.8	13.2	12.2	0.6	30	11.2	14.4	12.3	0.7	-0.704	56	>0.05
	R+L	60	10.8	13.3	12.1	0.5	50	10.3	14.4	12.2	0.8	-0.547	108	>0.05
FP	R	33	64.5	96.2	79.0	7.2	23	69.7	86.7	77.3	4.2	1.142	54	>0.05
	L	33	69.0	96.4	80.3	7.1	30	70.6	96.3	81.5	6.2	0.969	47	>0.05
	R+L	66	64.5	96.4	79.7	7.1	53	69.7	96.3	79.7	5.8	0.028	117	>0.05
TP	R	29	62.1	84.6	71.2	5.2	29	62.9	81.5	69.7	4.8	Mann-Whitney 337.000		>0.05
	L	27	58.6	78.6	69.0	4.7	27	60.0	80.0	67.2	4.7	Mann-Whitney 278.000		>0.05
	R+L	56	58.6	84.6	70.1	5.1	56	60.0	81.5	68.5	4.9	Mann-Whitney 1.244		>0.05

Table 58: Independent means t-test analysis comparing intra group laterality (Coastal group)

Note: (n) is the number of cases; Min is the minimum value; Max is the maximum value; Sd is the standard deviation; df is the degrees of freedom. All ages were pooled. Mann Whitney statistical test calculated when the independent t-test was not possible to be calculated due to a non-normal distribution.

Inland agriculturalists												t-test	df	p
Index		Females					Males							
		n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd			
HR	R	54	17.7	24.2	19.9	1.3	27	17.1	22.4	20.3	1.1	Mann-Whitney 500.000		0.022
	L	54	17.8	23.4	19.9	1.2	30	18.1	22.9	20.2	1.2	Mann-Whitney 718.000		>0.05
	R+L	108	17.7	24.2	19.9	1.3	57	17.1	22.9	20.2	1.2	Mann-Whitney 2423.500		0.025
FR	R	52	10.6	13.1	11.9	0.6	32	10.6	13.5	12.2	0.7	-2.576	82	0.012
	L	57	10.1	12.9	11.9	0.5	34	10.7	13.3	12.3	0.6	-3.091	89	0.003
	R+L	109	10.1	13.1	11.9	0.6	66	10.6	13.5	12.2	0.6	-3.875	173	<0.001
FP	R	60	67.7	109.1	81.2	8.2	36	69.4	96.7	82.7	6.1	0.903	94	>0.05
	L	61	63.6	93.1	82.7	6.4	35	72.7	103.5	85.7	6.7	-2.177	94	0.032
	R+L	121	63.6	109.1	82.0	7.4	71	69.4	103.5	84.2	6.6	-2.134	190	0.034
TP	R	58	57.6	84.0	68.5	5.9	33	48.7	93.3	67.6	8.7	-0.523	89	>0.05
	L	57	55.2	77.8	68.1	5.1	33	52.8	93.3	66.8	8.2	Mann-Whitney 743.000		>0.05
	R+L	115	55.2	84.0	68.3	5.5	66	48.7	93.3	67.2	8.4	Mann-Whitney 3.263		>0.05

Table 59: Independent means t-test analysis comparing intra group laterality (Inland group)

Note: (n) is the number of cases; Min is the minimum value; Max is the maximum value; Sd is the standard deviation; df is the degrees of freedom. All ages were pooled. Mann Whitney statistical test calculated when the independent t-test was not possible to be calculated due to a non-normal distribution.

Index		Coastal fishers					Inland agriculturalists					t-test	df	p
		Females					Females							
		n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd			
HR	R	21	17.6	22.1	20.0	1.2	54	17.7	24.2	19.9	1.3	Mann-Whitney 498.000		>0.05
	L	16	17.8	22.5	19.7	1.3	54	17.8	23.4	19.9	1.2	Mann-Whitney 388.000		>0.05
	R+L	37	17.6	22.5	19.9	1.2	108	17.7	24.2	19.9	1.3	Mann-Whitney 1938.000		>0.05
FR	R	32	11.1	13.3	12.1	0.5	52	10.6	13.1	11.9	0.6	1.930	82	0.048
	L	28	10.8	13.2	12.2	0.6	57	10.1	12.9	11.9	0.5	2.317	83	0.023
	R+L	60	10.8	13.2	12.1	0.5	109	10.1	13.1	11.9	0.6	3.014	167	0.003
FP	R	33	64.5	96.2	79.0	7.2	60	67.7	109.1	81.2	8.2	1.286	91	>0.05
	L	33	69.0	96.4	80.3	7.1	61	63.6	93.1	82.7	6.4	1.636	92	>0.05
	R+L	66	64.5	96.4	79.7	7.1	121	63.6	109.1	82.0	7.4	-2.066	185	0.041
TP	R	29	62.1	84.6	71.2	5.2	58	57.6	84.0	68.5	5.9	-2.110	85	0.038
	L	27	58.6	78.6	69.0	4.7	57	55.2	77.8	68.1	5.1	Mann-Whitney 701.500		>0.05
	R+L	56	58.6	84.6	70.1	5.1	115	55.2	84.0	68.3	5.5	Mann-Whitney 2640.000		>0.05

Table 60: Independent means t-test analysis comparing intra group laterality (Females)

Note: (n) is the number of cases; Min is the minimum value; Max is the maximum value; Sd is the standard deviation; df is the degrees of freedom. All ages were pooled. Mann Whitney statistical test calculated when the independent t-test was not possible to be calculated due to a non-normal distribution

Index		Coastal fishers					Inland agriculturalists					t-test	df	p
		Males					Males							
		n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd			
HR	R	21	18.9	23.4	21.0	1.4	27	17.1	22.4	20.3	1.1	-1.775	46	>0.05
	L	19	18.2	23.3	20.1	1.4	30	18.1	22.9	20.2	1.2	Mann-Whitney 282.000		>0.05
	R+L	40	18.2	23.4	20.5	1.4	57	17.1	22.9	20.2	1.2	1.082	95	>0.05
FR	R	20	10.3	14.3	12.1	0.9	32	10.6	13.5	12.2	0.7	0.599	50	>0.05
	L	30	11.2	14.4	12.3	0.7	34	10.7	13.3	12.3	0.6	-0250	62	>0.05
	R+L	50	10.3	14.4	12.2	0.8	66	10.6	13.5	12.2	0.6	-0174	114	>0.05
FP	R	23	69.7	86.7	77.3	4.2	36	69.4	96.7	82.7	6.1	-3.685	57	<0.001
	L	30	70.6	96.3	81.5	6.2	35	72.7	103.5	85.7	6.7	-2.620	63	<0.001
	R+L	53	69.7	96.3	79.7	5.8	71	69.4	103.5	84.2	6.6	-4.057	122	<0.001
TP	R	29	62.9	81.5	69.7	4.5	33	48.7	93.3	67.6	8.7	Mann-Whitney 392.500		>0.05
	L	27	60.0	80.0	67.2	4.7	33	52.8	93.3	66.8	8.2	Mann-Whitney 405.000		>0.05
	R+L	56	60.0	81.5	68.5	4.9	66	48.7	93.3	67.2	8.4	Mann-Whitney 1578.500		>0.05

Table 61: Independent means t-test analysis comparing intra group laterality (Males)

Note: (n) is the number of cases; Min is the minimum value; Max is the maximum value; Sd is the standard deviation; df is the degrees of freedom. All ages were pooled. Mann Whitney statistical test calculated when the independent t-test was not possible to be calculated due to a non-normal distribution

Comparisons of mean humeral and femoral robusticity between coastal and inland males were not significant (Table 61). Similar results were obtained for the tibial platycnemic index. The only significant results between both groups of males were obtained for the femoral platymeric index. These suggested that coastal males were more mechanically stressed than inland agriculturalists (mean value of 79.7 compared with 84.2).

5.7.3 Osteometric analysis according to age at death

The following Tables 62 - 63 provide information on the four post-cranial indices according to age at death. Table 62 shows the correlation among coastal fishers and Table 63 provides similar information for inland agriculturalists.

Index		Coastal fishers															Pearson	p
		Y-A					M-A					O-A						
		n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd		
HR	R	18	17.6	23.4	20.4	1.6	17	19.1	22.1	20.3	1.0	7	18.3	23.4	20.8	1.6	0.100	>0.005
	L	19	17.8	22.8	19.8	1.4	11	18.2	21.7	19.8	1.1	5	18.2	23.3	20.3	1.9	0.086	>0.005
	R+L	37	17.6	23.4	20.1	1.5	28	18.2	22.1	20.2	1.1	12	18.2	23.4	20.6	1.7	0.086	>0.005
FR	R	29	10.3	14.3	12.0	0.8	18	11.4	13.3	12.2	0.4	5	11.8	13.3	12.4	0.6	0.227	>0.005
	L	31	10.8	13.2	12.1	0.6	20	11.2	13.1	12.3	0.5	7	11.2	14.4	12.9	1.1	0.386	0.003
	R+L	60	10.3	14.3	12.0	0.7	38	11.2	13.3	12.2	0.5	12	11.2	14.4	12.7	0.9	0.315	0.001
FP	R	31	64.5	96.2	78.0	7.3	20	65.6	86.7	78.5	4.9	5	75.9	83.3	79.4	3.5	0.065	>0.005
	L	32	69.0	96.3	80.2	6.8	23	71.0	96.4	81.4	6.3	8	70.0	93.6	91.9	7.8	0.098	>0.005
	R+L	63	64.5	96.3	79.2	7.0	43	65.6	96.4	80.1	5.8	13	70.0	93.6	80.9	6.4	0.094	>0.005
TP	R	32	63.3	81.5	70.9	5.2	19	62.1	84.6	70.6	5.4	7	64.5	70.4	67.8	2.3	Kendall tau-b -0.115	>0.005
	L	29	58.6	80.0	68.4	5.4	19	62.9	78.6	68.5	3.8	6	59.4	70.0	65.4	3.5	Kendall tau-b -0.141	>0.005
	R+L	61	58.6	81.5	69.7	5.4	38	62.1	84.6	69.6	4.7	13	59.4	70.4	66.7	3.1	-0.150	>0.005

Table 62: Pearson correlation test between four indices and age at death (Coastal group)

Note: (HR) humeral robusticity (FR) femoral robusticity (FP) femoral platymeric (TP) tibial platycnemic (n) number of cases (Min) minimum value (Max) maximum value (Sd) standard deviation (df) degrees of freedom. Kendall's tau-b statistical test calculated when the distribution was not normal.

The femur was the only bone that became more robust and hypertrophic with age among coastal fishers, r=0.315, p=<0.005. On the contrary, the humeral robusticity, the femoral platymeric and tibial platycnemic indices did not show an increase in mechanical stress with increasing age. Kendall's tau-b correlation test revealed an indirect correlation at the platycnemic index, suggesting a decrease in mechanical workload in this bone with increasing age.

Index		Inland agriculturalists															Pearson	p
		Y-A					M-A					O-A						
		n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd	n	Min	Max	Mean	Sd		
HR	R	31	17.7	24.2	19.9	1.4	37	17.1	22.4	20.0	1.3	13	19.4	21.6	20.2	0.7	Kendall tau-b 0.124	>0.005
	L	29	17.8	22.9	19.8	1.5	39	17.8	23.4	20.0	1.1	16	19.0	21.9	20.5	1.0	Kendall tau-b 0.202	0.019
	R+L	60	17.7	24.2	19.9	1.4	76	17.1	23.4	20.0	1.2	29	19.0	21.9	20.4	0.8	Kendall tau-b 0.160	0.009
FR	R	30	10.6	12.9	11.6	0.7	41	11.3	13.5	12.3	0.6	13	10.8	13.1	12.1	0.6	0.329	0.002
	L	30	10.1	12.7	11.7	0.6	44	11.5	13.3	12.2	0.5	17	11.1	13.3	12.1	0.6	0.334	0.001
	R+L	60	10.1	12.9	11.6	0.6	85	11.3	13.5	12.2	0.5	30	10.8	13.3	12.1	0.6	0.334	<0.001
FP	R	34	67.6	89.7	79.5	6.0	46	67.7	96.7	82.9	6.7	16	68.6	109.1	83.5	11.1	0.215	0.036
	L	33	65.6	92.9	82.1	7.2	46	75.8	103.5	84.9	6.1	17	63.6	93.1	84.2	6.6	Kendall tau-b 0.127	>0.005
	R+L	67	65.6	92.9	80.7	6.7	92	67.7	103.5	83.9	6.5	33	63.6	109.1	83.8	8.9	0.180	0.013
TP	R	33	58.6	84.0	67.9	6.1	43	48.7	93.3	67.9	7.8	15	57.6	83.3	69.3	6.8	0.054	>0.005
	L	32	59.3	77.8	67.1	5.3	44	52.8	93.3	67.3	7.2	14	57.6	83.3	69.9	6.2	0.120	>0.005
	R+L	65	58.6	84.0	67.5	5.7	87	48.7	93.3	67.6	7.4	29	57.6	83.3	69.6	6.4	0.085	>0.005

Table 63: Pearson correlation test between four indices and age at death (Inland group)

Note: (HR) humeral robusticity (FR) femoral robusticity (FP) femoral platymeric (TP) tibial platycnemic (n) number of cases (Min) minimum value (Max) maximum value (Sd) standard deviation (df) degrees of freedom. Kendall's tau-b statistical test calculated when the distribution was not normal.

Upper and lower limb robusticity among inland agriculturalists showed a direct correlation of humeral and femoral robusticity indices with increasing age. The femoral platymeric index showed a positive correlation with increasing age $r=0.180$, $p <0.005$ and the tibial platycnemic index did not correlate with increasing age.

Chapter 6:

Discussion

Chapter 6: Discussion

In this chapter the results obtained for the five activity-related skeletal changes and the osteometric analysis are discussed as presented in Chapter five according to sex, age at death and laterality. The results for these markers are discussed and possible explanations for the patterns found are explored. The patterns found are also compared, whenever possible, with data from other studies of Native American Indians that practised a similar subsistence economy as that of the studied populations.

6.1 Enthesophytes

6.1.1 General comparisons between coastal and inland samples

General comparisons between both populations suggested that, on the basis of the total number of entheseal areas analysed, inland agriculturalists were significantly more affected by enthesophytes than coastal fishers (Table 25).

On the basis of these results it could be suggested that the agricultural way of life practised by inland agriculturalists during the middle and late intermediate period in northern Chile would have caused higher mechanical demands and more physical stress at most insertion sites of the upper and lower limbs of the body. According to the findings of this study, marine hunting and gathering, on the other hand, appeared not to have resulted in such high muscular demand. These results appear to contradict those obtained with osteoarthritis (Table 34), spondylolysis (Table 43) and to some extent (although not supported statistically), os acromiale (Table 49) and osteochondritis dissecans (Table 55). Furthermore, these results also contradict the studies of Rogers *et al.* (2004) and Molnar *et al.* (2009) where the analysis of enthesophytes and osteoarthritis showed that both conditions tend to correlate and indicate a relationship. Firstly, the explanation for the lack of relationship between both variables could be due to the method used to group each separate enthesis together with others that performed a similar or mutual function. As described in Chapter four (section 4.2.2) the way of grouping enthesophytes may have not matched the function of similar anatomical areas considered for osteoarthritis, thus creating lack of correlation between both conditions.

Similar studies where populations with subsistence economies like those of the coastal fishers and inland agriculturalists are compared have not been conducted. Nor have studies of this nature aiming to assess the transition from one form of economy to another. Therefore, it is hoped that this study will help to set the basis for future comparative studies on enthesophytes involving populations that practised two contrasting subsistence economies such as those of the Chinchorros and the inland agriculturalists.

6.1.2 Enthesophytes according to sex

The data for enthesophytes according to sex suggested that intra-group comparisons among coastal Chinchorros showed a variation in prevalence rates for most individual entheses analysed (Table 26). Males were significantly more affected than the females at the shoulder and elbow areas but females were significantly more affected at the hip. However, on the basis of total true prevalence rates, Chinchorro males were significantly more affected by enthesophytes than the females. This pattern was consistent with the data obtained for spondylolysis (Table 45) and to some extent to that of os acromiale (Table 51), although as this condition was absent in all female scapulae analysed, the statistical test failed to demonstrate a significant difference between the sexes.

In line with marked sexual differences in enthesophyte prevalence rates between Chinchorro males and females, the studies of Hawkey and Merbs (1995), Wilczak (1998) and Steen and Lane (1998) also showed significant sexual dimorphism in skeletons belonging to Eskimos who practised a similar subsistence economy to that of the Chinchorro people (marine hunting and gathering). The former authors observed that females utilised muscles involved in flexion/extension of the forearm and adduction of the arm, whereas males tended to show larger muscle attachments involved in rotation and pronation of the arm. Wilczak (1998) found that male Aleut Eskimos displayed significantly larger muscle attachments at the humerus compared with females. Despite the genetic patterns that might have played a role, the author suggested that climate may have also played a role in the sexual division of labour as certain activities that require a high degree of mobility tend to be assigned to males whereas females can be less mobile due to child care demands. Steen and Lane (1998) observed that Goloving and Nunivak male Eskimos displayed significant differences in a number of upper limb enthesophytes when compared with their female counterparts, although these differences were insignificant in the lower limb muscle attachments of the Nunivak group only.

Despite how illustrative these examples might be, it should be recognised that these studies were carried out using a different methodological approach as that performed in this study and therefore the results obtained here should be interpreted in the light of the particular context of the Chinchorro way of life. For instance, as discussed in Chapter three (section 3.2.2) Standen (2003) observed that on the basis of grave good analysis, Chinchorro males and females played different roles in society. Women were associated with fishing tools used to catch small fishes (fishhooks, fishing weights and fishing lines), while men were associated with tools for hunting larger sea mammals (arrow shafts and harpoon barbs). The Spanish chronicler Gerónimo de Bibar, who in 1558 observed the local coastal populations of northern Chile wrote, "*los que matan lobos no matan otros peces, como habemos dicho, y los que matan toninas es en ejercicio. Así que cada género de pescador mata el género de pescado a que se aficionan y no a otro; y cuando muere manda que encima de su sepultura pongan las calavernas (calaveras?) y todos los instrumentos de pescar ansi redes como arponcillos y anzuelos sin lengüeta*" (Bibar, 1966 [1558]:12). This can be translated as "the individuals who specialise in killing sea lions do not kill other fish and those that kill small dolphins are specialists. Hence each type of fishermen kills the type of fish in which he has become expert and not any other. When the person dies, they put inside his grave his fishing toolkit as well as fishing nets and small harpoons". These observations were not based on activities practised by the Chinchorro people but on populations who had settled in coastal areas of northern Chile during the sixteenth century. However, if coastal exploitation remained consistent and unchanged over millennia, as suggested by Arriaza (1995a), it is possible that professionals existed within this society who performed specific tasks throughout their lives. This assumption would therefore have consequences for the division of labour and the manifestations of enthesophytes according to sex.

Although the analysis of grave goods can provide insights on sexual division of labour in past populations, these should be handled with caution. In the case of the Chinchorro people, it could be hypothesised that, instead of representing personal belongings indicative of the allocation of tasks or social rank, these items could have likewise represented offerings or gifts given by relatives or friends. The fact that items such as harpoon heads, which are associated with hunting activities, were part of the funerary remains of individuals of both sexes and all age categories would give rise to questions about the reliability of these items as indicative of sexual division of labour and ranking, especially when buried with infants and young children who would have been very unlikely to have used them for hunting purposes.

The enthesophytes results along with those of spondylolysis and os acromiale, which are summarised by Ponce (2010) and which will be discussed in the next sections, would all give support to the suggestion that Chinchorro males and females played different roles in society. Other evidence of a sex division of labour comes from indirect evidence of external auditory exostosis, an activity-related condition believed to result from diving and swimming in cold waters (Standen *et al*., 1995). These authors observed that this condition was present in a higher prevalence among Chinchorro males (69.2%, 18/26) compared to females (19.2%, 5/26), suggesting that men were more likely than women to be engaged in activities that required immersing the head and ears during swimming such as gathering molluscs and other seafood resources.

As shown in Table 26 the significant differences observed in the enthesophytes of the shoulder and elbow in men would give support to the idea that they were responsible for hunting big game as this activity would certainly require strength and strong musculature in the upper limbs. However, it is difficult to confirm if these were produced solely from hunting activities as discussed in Chapter two (section 2.1.4) as enthesophytes can be the result of a number of different variables.

Furthermore, the results obtained by the metric analysis (Table 58) would also give partial support to the variation found in the upper limb enthesophytes. Chinchorro men were significantly more robust in their right humerus compared with females, although no significant difference between the sexes was observed in the left humerus.

Despite the trend observed in the entheseal and metric data it should be remembered that, as mentioned earlier, Standen (2003) found harpoon heads associated with all individuals from both sexes and all ages, thus questioning the reliability of this grave goods information to analyse sexual division of labour.

Inland agriculturalists, on the other hand, showed less intra-group variation in individual prevalence rates for enthesophytes (Table 27). The only exception was found at the knee, where males had significantly more enthesophytes (78.9%, 235/298) than the females (71.0%, 365/514) in this area. Total true prevalence rates also followed this trend as there was no statistical difference between the sexes. This pattern was consistent with the results obtained with osteoarthritis (Table 36), spondylolysis (Table 46), os acromiale (Table 52) and to some extent osteochondritis dissecans (Table 55).

These results are consistent with the suggestion made by Wilczak (1998) that reduced sexual dimorphism at different muscle insertion areas is compatible with populations that practised agriculture. In for different studies, Wilczak (1998) with Hawikuh people, a Native American population from New Mexico (USA), Al-Oumaoui *et al.* (2004) with skeletons belonging to individuals of La Carada, an Early Copper Age settlement in Granada (Spain), Molleson (1989) with Mesolithic skeletons from Syria, and Peterson (2002) with Neolithic skeletons from southern Levant, data were all consistent with the absence of enthesophyte differences between the sexes among agricultural populations. The absence of differences in enthesophyte patterning between inland agriculturalists would indicate that both sexes practised physical activities that involved a similar mechanical stress. As observed by Peoples and Bailey (2009), in those societies that rely heavily on intensive agriculture, (i.e. on growing cereal crops such as wheat and corn and relying on livestock for meat, dairy products, hides and wool), men would concentrate more on farm work, performing heavy duties such as ploughing the soil. Women's roles, on the other hand, would involve spending less time in the field but would concentrate on domestic work, including food processing and preparation before cooking. In horticultural societies where the subsistence relies on growing root crops like yams, sweet potatoes or manioc, and where cultivation tasks are spread more evenly over the year, women get more involved in direct food production. Men instead would focus on hunting, or where war was prevalent, they would maintain the community defences and guard against the arrival of potential enemies.

Inland agriculturalists would probably have been involved in a combination of these systems as the archaeological evidence suggests that both root and cereal crops were cultivated by these people. Thus, despite the possible variations, both sexes would have probably participated in agricultural activities as well as practising other activities such as weaving, basketry, making pottery and metal work, fishing, herding camelids, among others. The sexual division of labour and the allocation of tasks among inland agriculturalists might have been influenced by a number of variables including status, position in the society and these might have also changed diachronically during a person's life. It could be hypothesised that the absence of differences in enthesophyte patterning between the sexes resulted from practising physical activities that involved equal mechanical stress, although other alternative explanations such as both sexes being subjected to similar systemic stress cannot be rejected. The fact that these results were consistent with those obtained with other markers of occupational stress, would give support to the former idea.

Finally, the analysis of grave goods according to sex as shown in Table 9 and discussed in Chapter three (section 3.3.2), and from which social aspects of sexual division of labour could be inferred, suggested that different roles might have been played between the sexes. Women were clearly associated with the textile industry and a large number of males were associated with high status items as well as items belonging to metallurgy and warfare. On the other hand, the reliability of this source of information is questionable when hunting equipment such as arrows, harpoon heads and arrow heads were found associated with both sexes and when men were found associated with food processing items such as mortars.

One possible explanation for these findings is the unreliability of the documentation. This is in part due to the inconsistency found between the catalogues and records hold today by the Museo Arqueológico San Miguel de Azapa and the original list of material excavated by Focacci, Santoro and Muñoz during the early 80's. Numerous items listed in the original records have been lost or remain today uncatalogued in the storage rooms and likewise, numerous items present today in the catalogues of the Museum are not described in the original fieldwork notes. As explained in Chapter three (section 3.3.2) the information on grave goods was gathered by pooling information from both sources, hence giving a possible explanation for the unexpected findings.

Another explanation (discussed above) is that grave goods, instead of representing personal belongings of the deceased as suggested by Muñoz (2004), could have been offerings given by relatives or friends, thus suggesting little connection with sexual division of labour, status and rank. A final hypothesis that should not be totally rejected is that female agriculturalists were also involved in hunting activities and for that reason they were found with hunting equipment.

In summary, these results suggested that both agricultural men and women showed no difference in the prevalence of enthesophytes of the upper and lower limbs. This pattern could demonstrate that agricultural tasks might have been shared between men and women, although it should not be forgotten that this was a complex society with professionals that performed numerous activities so the contribution of these to the formation of enthesophytes and the final expression between the sexes would be difficult to evaluate. The study of Standen *et al*. (1995) analysing the presence of external auditory exostosis among inland populations from the Azapa valley would give strength to the idea that men and women shared a number of subsistence tasks. The authors analysed 264 crania from a number of inland individuals buried at various cemeteries and found that unlike coastal fishers, both sexes were equally affected by this condition (1.9%, 3/154 females compared with 2.7%, 3/110 males).

Inter-group sex comparisons (Table 28) showed that females from both populations exhibited more variation than that observed between coastal and inland males. On the basis of total true prevalence rates, inland females were significantly more affected than Chinchorro females. On the other hand, total true prevalence rates showed no differences in the patterning of enthesophytes between males. On the assumption that these findings are related to workload and physical activity, the mechanical stress involved in hunting and gathering marine fauna as well as practising agriculture appear to be similar for males but different for females. If, as discussed earlier, inland females and males showed no marked sex-based differences in enthesophyte patterning, while seeing a marked difference among coastal Chinchorros then, on the basis of inter-group sex comparisons, these data emphasise the sexual division of labour found among coastal males and females. On the other hand, a variety of other mechanisms that are not necessarily activity-related and sex-based such as age, hormonal changes and normal variation of bone responding to stress could have also played a role.

6.1.3 Enthesophytes according to age at death

The analysis of enthesophytes according to age showed that, on the basis of total true prevalence rates, coastal fishers were more affected than inland agriculturalists in the young and middle age categories with reverse results for the old adult age group (Table 29). However, a Chi-square test revealed that comparisons were only statistically significant in the middle age category. Although not always supported statistically, these findings were consistent with the data obtained for osteoarthritis, spondylolysis and os acromiale according to age, where coastal Chinchorros presented higher prevalence rates compared to inland agriculturalists (Tables 37, 46-47, and 52-53).

Analysis of individual enthesophytes showed that the earliest manifestations of this condition appeared at the elbow joint, and coastal Chinchorros were significantly affected compared to inland agriculturalists. These data were also consistent with those found for osteoarthritis (Table 38).

To summarise, if physical activity and occupation are the main factors responsible for triggering the formation of enthesophytes, then this data suggests that the marine hunting and fishing lifestyles of coastal Chinchorros were more strenuous and physically demanding than that practised by later agricultural populations. It could also be implied that this demanding lifestyle for coastal Chinchorros started at a younger age exerting higher mechanical stress on the elbows compared to inland agriculturalists. The absence of significant differences between both groups in the old adult category would suggest that, perhaps towards older adulthood, individuals were no longer participating regularly in physical activities that younger coastal and inland people. However, a reduction in the number of old adult individuals with available enthesophytes for study could equally explain the results obtained. Finally, it should be borne in mind that these interpretations are based on the assumption that enthesophytes respond only to physical activity and mechanical stress. However, as reviewed in Chapter two, section 2.1.4 enthesophytes can form in response to a number of factors, and some of them are of a systemic nature such as age. Indeed, this study showed that, on the basis of total true prevalence rates, enthesophytes were positively correlated with increasing age in both coastal and inland groups (Tables 30 - 31). A number of bioarchaeological studies from both Old and New World populations (Rogers *et al*., 1997; Weiss, 2003; Mariotti *et al*., 2004; Toyne, 2004; Alves Cardoso, 2008) as well as clinical studies (Woods *et al*., 2002; Kalichman *et al.*, 2007) support these findings. If enthesophytes correlate with age, as shown by this study and that of others, then these markers might not necessarily be appropriate to choose to evaluate occupational stress. Although their connection with physical activity cannot be denied, the strong link with age as an aetiological factor, could indicate that they might be useful markers providing they are used along with others. For this reason the explanations presented above should not be considered as a final statement of fact.

6.1.4 Enthesophytes according to laterality

No side dominance of enthesophyte prevalence was observed in any of the upper and lower limb entheseal areas in both coastal and inland groups (Tables 32 – 33). The data for enthesophytes and laterality was reflected in the patterns of osteoarthritis and were also supported by those obtained in the upper limbs for os acromiale (Tables 41 - 42, 48). To some extent, the results obtained for osteochondritis dissecans among coastal fishers (Table 55) were also consistent with the above, but as this condition was represented by just one individual (both knees), it will not be used to support the other data.

Studies carried out in the fields of kinesiology, sports medicine, occupational medicine, biomechanics and applied anatomy have indicated that the link between enthesophytes and laterality is an important consideration because symptoms usually manifest in the dominant extremity (Eller *et al*., 1992; Cain and Dugas, 2004). Clinical studies, however, have not focused their attention on the lateral expression of these skeletal changes because clinicians and orthopaedic surgeons have been more concerned about other clinical aspects of enthesophytes, including diagnosis and treatment.

In bioarchaeology, it has been suggested that in populations whose main subsistence economy was based on hunting, gathering and foraging, the use of harpoons, spears, atlatl or bow and arrow would lead to asymmetrical stress of the upper limbs, with pronounced expression of enthesophytes on the dominant arm (Peterson, 1998, 2002). For instance, a number of studies have been carried out with skeletons of Canadian Eskimos for which the ethnographic data describes the use of these tools and type of subsistence economy. These studies support the idea of asymmetrical distribution of upper limb enthesophytes (Merbs, 1983; Hawkey and Merbs, 1995). However, none of these studies appeared to have tested this hypothesis statistically.

Bilateral asymmetry among coastal Chinchorro showed that right hand side enthesophytes of the upper limbs located at the shoulders and elbows were more affected than those from the left side (Table 32). Despite this finding and the assumption that the Chinchorro people might have been predominantly right handed, this trend was not supported statistically. In line with these results, Steen and Lane (1998) did not detect right or left side entheseal predominancy in either the Golovin or Nunivak Eskimo populations from Alaska. It could be hypothesised that despite the unilateral strength involved in throwing a spear or harpoon, the enthesophytes formed by both unilateral and bilateral use may obscure the signs of side preference, if they really existed during life. Furthermore, as reviewed in Chapter three (section 3.2.1) it should also be highlighted that although the Chinchorro people were mainly marine hunter and gatherers, their activities and occupations also involved a number of physical activities that could have implied equal usage of both arms. For instance, gathering wild plants for consumption and vegetable fibres to weave baskets, as well as knitting fabrics and the development of early horticulture which was present towards the final period of the Chinchorro culture, as evidenced in cemetery Quiani 7 (Chapter three, section 3.2.4).
The osteometric analysis (Table 56) showed inconsistent results with those found for the coastal Chinchorros. For instance, the right humeri of coastal individuals were significantly more robust than the left. The reason behind these conflicting results

perhaps can be explained by other variables influencing the expression of laterality among coastal Chinchorros, such as sex and perhaps age at death. As found by other authors (Ruff *et al*., 1993), the symmetrical expression of these skeletal markers might not necessarily go in line with the geometric properties of bone because even moderate workload can potentially reflect asymmetrical diaphyseal bone changes without leading immediately to the formation of enthesophytes.

In bioarchaeology it has also been suggested that populations whose subsistence economy was based on agriculture were more likely to present, at least for their upper limbs, a symmetrical distribution of enthesophytes compared with hunter-gatherers and foragers (Peterson, 2002). The studies of Molleson (1989) with Mesolithic skeletons from Syria, Peterson (2002) with Neolithic agricultural populations from Jordan and Israel and al-Oumaoui *et al.* (2004) with agricultural populations from Spain suggested that the tasks involved in agricultural activities implied bilateral use of the limbs. Using hoes, ploughs, adzes and axes as well as plant food processing tools such as pestles and mortars would involve significant forearm flexion and extension and imply the bilateral use of both arms according to these authors.

Inland agriculturalists followed this trend and the osteometric analysis (Table 56) supported these results. Despite the time that this group might have invested in agricultural chores, it should not be disregarded that enthesophytes could have been produced by many other activities practised by these groups that could have equally contributed to the development of symmetric musculature. For instance, as reviewed in Chapter three (section 3.3.1) inland agriculturalists also practised weaving, knitting, mining preparation, production of clay and ceramic and smelting metals. In addition, inland agriculturalists complemented their diet with activities such as hunting using the bow and arrow, believed by many to produce asymmetric distribution of upper limb enthesophytes.

In summary, coastal fishers and inland agriculturalists might have been involved in a number of different activities that their particular subsistence economies required. These tasks did not lead to any statistically significant side dominance in the upper and lower limbs as reflected in the results obtained with osteoarthritis. If the aetiology of enthesophytes was only related to physical activity, then it could be suggested that equal mechanical stress was placed on both sides of the upper and lower limbs of the body and that physical activities required symmetrical strength in these populations. However, as mentioned earlier in Chapter two (section 2.1.4) and emphasised here again, the aetiology of enthesophyte formation is multifactorial and therefore its presence cannot be explained solely by physical activity and occupation.

6.2 Osteoarthritis

6.2.1 General comparisons between coastal and inland samples

General comparisons between both populations suggested that, on the basis of the total number of joints analysed, coastal fishers were statistically more affected by osteoarthritis than inland agriculturalists (Table 34). A similar trend was found for the data obtained for spondylolysis (Table 43) and to some extent (although not statistically significant) os acromiale (Table 49) and osteochondritis dissecans (Table 55).

On the basis of these results it could be suggested that a marine hunting and gathering subsistence economy practised by the Chinchorro people during the archaic period would have implied higher mechanical demands that lead to erosion and degradation of their upper and lower limb joints. The agricultural way of life on the other hand, appeared, according to these findings, not to have resulted in such a negative effect on joints.

These results go in line with other studies carried out by Larsen (1984), Jurmain (1990), Larsen *et al.* (2007), Danforth *et al.* (2007) with North American populations and that of Rojas-Sepúlveda *et al*. (2008) with South American populations, where with the arrival of agriculture a decrease in osteoarthritis was evident. Comparisons of these studies with the coastal and inland samples are not straightforward because the joints analysed and the methods applied were not always the same. However, these studies are useful comparative examples because the assessment of this economic shift involved comparisons of OA in a similar set of joints from individuals of the same region but different time periods and subsistence economies, as well as comparisons of prehistoric foragers and farmers from different settings.

6.2.2 Osteoarthritis according to sex

The data for OA according to sex revealed that intra-group comparisons among coastal Chinchorros showed no sex-related variation of prevalence rates for all individual joints analysed (Table 35). Total true prevalence rates showed that OA was more prevalent among Chinchorro males (32.2%, 146/453) compared with their female counterparts

(29.4%, 136/463), but statistical analysis failed to support a significant difference between them. These results were consistent with those for the analysis of OA and laterality (Table 41) and with the data for robusticity, platymeric and platycnemic indices taken on the humeri, femora and tibiae, with the only exception of the right humeral robusticity index where males appeared to be more robust than the females. These results would therefore suggest that, regardless of sex, handedness, and robusticity, Chinchorro males and females were equally affected by OA. On the other hand, a marked sex difference between these groups was evident for other skeletal markers, including enthesophytes (Table 26), spondylolysis (Table 45) and os acromiale (Table 51).

With regard to sex differences in OA, Larsen (2002) suggested that a higher prevalence of OA in males than in females is a nearly universal concept as workload and mobility was greater in men than in women in past societies. This premise is consistent with the results of Merbs (1983) with the Sadlermiut Eskimos from Canada where males showed a consistently higher prevalence of OA in all upper and lower limb joints compared to females. However, Merbs did not test his findings statistically, hence questions remain regarding the significance of these findings or whether they resulted merely from a stochastic process. In line with the study of Merbs, Jurmain (1990) analysed the elbow, shoulder, knee and hip joints in 140 skeletons belonging to Eskimos and found that males were more affected than females although these results were not tested statistically. Another study worthy of mention is that of Standen *et al.* (1984) who analysed sex differences in OA among Chinchorro individuals buried at the cemetery of Morro 1. This author observed that OA of the knees, the elbows, the costo-clavicular and acromio-clavicular joints revealed that males (10.8%, 7/65) were more affected than the females (7.7%, 5/65).
The present study supported the suggestion of Larsen (2002) and although the results obtained by Merbs (1983), Jurmain (1990) and Standen *et al.* (1984) also did, these studies cannot be directly compared with the results found here as differences were evident in terms of the joints chosen for analysis, the methods used for recording OA, and the prevalence calculations.

As reviewed in Chapter two (section 2.2.4), the premise of a higher prevalence of OA among males has also been supported by modern clinical studies, although men tend to be more affected by the condition up to the age of about 50-55 years, after which the situation tends to reverse in the older age groups; women then become more affected with polyarticular OA in five or more joints, particularly those of the hand (Srikanth *et al.*, 2005; Andrianakos *et al.*, 2006). According to Resnick (2002e) the reasons for these male/female differences in the distribution and patterning of OA are unresolved, but hormonal changes (Jones *et al*., 2002; Cooley *et al*., 2003) and genetics (Doherty *et al*., 2000) are important determining factors. As modern populations tend to live longer than past populations, the male/female differences in the distribution and patterning of OA would be difficult to explore in these Chinchorro populations, particularly when, as observed in the demographic profile (Table 24), only a small percentage of the population lived longer than 50 years of age.

In bioarchaeology, on the other hand, sexual differences in the prevalence of OA have been linked with sexual division of labour (Merbs, 1983; Arriaza, 1995a; Standen *et al.*, 1984; Peterson, 2002). The study of Standen (2003) based on grave good analysis between Chinchorro males and females and the results obtained in this study with enthesophytes (Table 26) would give support to the idea of these individuals playing different roles in society. Contrary to these observations OA did not show differences between Chinchorro males and females, thus contradicting this idea. Many hypotheses could be argued, for instance, it could be suggested that osteoarthritis affected both sexes regardless of how different the allocation of tasks were distributed between the sexes and therefore it could be assumed that the expression and manifestation of enthesophytes might not necessarily follow the same pattern observed in OA. Secondly, it could be suggested that at least in this case the use of upper and lower limb muscles did not contribute proportionally to the development of OA in these areas of the body. It could also be suggested that osteoarthritis affected males and females regardless of their activities and occupations practised, whether these were different roles or shared tasks or different roles that involved equal stress. This would point to a different aetiology between enthesophytes and OA where physical activity and occupation was not similarly involved.

Intra-group comparisons among inland agriculturalists showed no sex-related variation in prevalence rates for all individual joints analysed (Table 36). Total true prevalence rates showed that OA was more prevalent among females (26.7%, 158/967) compared to males (24.5%, 142/580); however, no statistically significant difference was observed between them. These results were consistent with the results obtained for enthesophytes (Table 27), spondylolysis (Table 46) and os acromiale (Table 52).

Whereas the presence of OA in coastal fishers has not been systematically studied, the only other studies available where this condition is addressed among inland agriculturalists is discussed by Allison (1984) and Muñoz (2004). These authors focused on osteoarthritis of the spine, but because this area of the body was not chosen for analysis of OA in this study, their results and those found here are not comparable.

Other bioarchaeological studies carried out on populations whose subsistence economy was mainly agriculture have demonstrated different patterns in sex distribution for OA. For instance, Ubelaker and Newson (2002) worked on skeletons of agriculturalists from the south coast of Ecuador and, on the basis of true prevalence rates, the authors found that women were slightly more affected by OA in the shoulder and elbow joints, as well as in the lumbar vertebrae, indicating that this pattern could be related to the process of grinding maize and also that women were probably the cultivators; they were all affected with thoracic OA suggesting they may have been involved in more bending and lifting. In a different study, Hutchinson *et al.* (2007) observed that vertebral OA among the inner coastal farmers of North Carolina (USA) appeared to be highly prevalent among males compared to females. From the total vertebrae observed, 80% of men were affected mainly in the lumbar area, compared with 20% of the females who were mostly affected in the cervical area. Finally, Rojas-Sepúlveda *et al*. (2008) found no significant differences in spinal OA among the agriculturalist Muisca people from Colombia as both sexes were similarly affected in the spine.

As these studies have demonstrated the premise of a universally higher prevalence of OA among males, as suggested by Larsen (2002), does not necessarily apply to all prehistoric groups and certainly does not apply to the populations analysed here. If sexual division of labour is the reason that explains the different patterns of OA between the sexes, as suggested by Merbs (1983), Arriaza (1995a), Standen *et al*. (1984) and Peterson (2002) then, on the basis of the data obtained from study of the inland agriculturalists, it could be suggested that both sexes performed physical activities and occupations that were equally demanding and stressful for both sexes. The results obtained by Standen *et al*. (1995) with the analysis of external auditory meatus among these populations and according to sex would give strength to this idea.

The analysis of grave goods among inland agriculturalists (Table 9), from which social aspects of sexual division of labour could be addressed, suggested that allocation of tasks according to sex might have been present among these populations. Engaging in agricultural activities such as clearing the soil, ploughing, seeding, and harvesting that require upper body and vertebral strength might have been important determinant activities in the aetiology of osteoarthritis. However, the information on grave goods provided little evidence to understand how each sex was involved in this task. Similarly, hunting activities that would have also required repetitive movements of the upper body did not provide conclusive information as to how this activity was performed according to sex. The textile industry which appears to have been a female activity per excellence would have been consistent with repetitive movements of the arms and spending long hours sitting. At a glance, with the only exception of the elbow joint, inland females were more affected at all joints by OA compared with males (Table 36), but as this comparison was not statistically significant, it could be summarised that OA affected both sexes regardless of the difference in tasks performed according to sex.

In conclusion, intra-group sex comparisons among these Chilean coastal and inland populations revealed that, when total true prevalence rates for OA were compared, no statistical differences were found between the sexes for both groups. Consistent with this, no differences were found when a comparison was made according to each separate joint. Therefore, if osteoarthritis resulted solely as a consequence of physical activity and occupation, it could be argued that performing activities related to fishing and hunting marine fauna placed equal stress on the upper and lower joints of coastal males and females. In a similar way, it could be argued that the practice of activities related to agriculture placed equal stress on the upper and lower limb joints of inland agriculturalists of both sexes. A final idea could also be suggested, on the basis of the results found in both populations, OA affected prehistoric men and women equally regardless of the activity they practised as seen in modern populations. This would imply that physical activity and occupation has little connection with the aetiology of the condition and perhaps other underlying factors, as reviewed in Chapter two (section 2.2.4), which are not necessarily activity-related or sex-based such as age, hormonal changes, genetics, obesity and diet could have had a more important impact. The specific contribution of physical activity to the expression of this condition among these populations would be difficult to identify and therefore the findings should be interpreted cautiously.

In line with the results obtained for intra-group comparisons, inter-group sex comparisons also showed that, on the basis of total true prevalence rates there was no difference in the patterning of OA between the sexes for both coastal fishers and inland agriculturalists (Table 37). With the only exception of the hip joint which was significantly more affected in coastal males compared to inland males, the analysis of individual joints also showed no significant differences in involvement among these populations. With particular attention to this joint, Waldron (1995, 1997) and Baetsen *et al.* (1997) suggested that the pattern of hip OA has changed over time, indicating a steady decrease in prevalence rate from the early pre-medieval period to the modern period in European populations. This temporal trend in the prevalence of OA has led a number of scholars working with skeletons from Native American populations to propose that, with the shift from a subsistence economy based on hunting and gathering to agriculture, there was a decrease in the condition (Walker and Hollimon, 1989; Larsen *et al.*, 2007; Danforth *et al.*, 2007). On the other hand, Hutchinson *et al.* (2007) and Marquez Morfín and Storey (2007) observed a temporal increase in OA. In northern Chile, Arriaza (1995a) found that spinal OA seen in the Chinchorro people was "milder" compared to that of later agricultural groups, and it was not apparent in earlier ages (early 20's) for these groups, compared to people 30 years or older in the coastal fishers, thus suggesting an increase in OA with age. The present study showed that with the arrival of agriculture and on the basis of total true prevalence rates, the presence of OA decreased from that seen in archaic coastal Chinchorros to later agriculturally-based populations, thus contradicting the results obtained by Arriaza (1995a). As suggested earlier, the reason for this discrepancy could be found in the different joints analysed and the different methods used for recording the condition and for calculating prevalence rates.

6.2.3 Osteoarthritis according to age at death

The data on OA according to age at death showed that, on the basis of total true prevalence rates, coastal fishers were significantly more affected by OA than inland agriculturalists for the young and middle age categories (Table 38). The opposite was found for the old adult age category, although this was probably because there were only a few individuals and joints available for study within the old adult group (>50 years) of coastal fishers. It can also be suggested that coastal Chinchorro did not live long enough to manifest OA as, according to Alfonso *et al*. (2007), there appeared to be an increase in life expectancy during the Middle Period of northern Chile (Table 8) compared to early populations, thus influencing longevity and the chances of developing and manifesting OA.

Although not always supported statistically, these findings were consistent with the data obtained for enthesophytes (Table 29), spondylolysis (Tables 47 - 48) and os acromiale (Tables 53 - 54) according to age, where coastal Chinchorros presented higher prevalence rates compared to inland agriculturalists. The analysis of individual joints showed that the earliest manifestations of this condition appeared at the elbow and hip joints of the Chinchorros. These data were also consistent with those found for enthesophytes (Table 29) although for the entheseal areas of the elbow only. Towards middle adulthood, coastal fishers were more affected by OA in all joints, with the exception of the ankle. In the old adult age group, there were no significant differences in the prevalence rate for OA between both groups, with the only exception of the hip joint.

As reviewed earlier, Arriaza (1995a) found that degenerative changes observed among the coastal populations did not start at such a young age compared with later agricultural populations from Arica. The present study, on the contrary, demonstrated that coastal fishers exhibited a significantly earlier onset of the condition with a total true prevalence rate of 15.0% (71/474) among the young adults compared with 5.5%

(30/544) in the inland agriculturalists (X^2 25.386 $p<0.001$). The differences in results between this study and that of Arriaza (1995a) are probably due to the fact that the author compared the manifestation of OA between both populations by using the spine, and probably a different method to score the condition. Furthermore, as discussed in section 6.1.3 of this chapter, true prevalence rate calculations for enthesophytes would also indicate an early onset among the coastal group, therefore giving support to the results found here for OA.

Similar to the Chinchorro who practised fishing and hunting marine fauna, Jurmain and Kilgore (1995) reported that Eskimo groups also show an early age of onset for elbow OA when they compared their data with Pueblo Indians and central California Indians. Consistent with this analysis, and according to a study conducted by Jurmain (1977) with skeletons of Alaskan Eskimos and Pueblo Indians, and with two contemporary groups belonging to modern black and white Americans, the former group appeared to be the population with the earliest age of onset for the investigated joints (shoulder, elbow, hip and knee).

In conclusion, if the patterning of OA according to age at death was only related to physical activity, it can be suggested that the lifestyle and occupations of archaic marine hunter and gatherers were significantly more demanding for the upper and lower limb joints when compared with populations whose subsistence economy was based on agriculture. It could also be suggested that taking part in subsistence activities, as indicated by the early onset of OA among Chinchorro people, occurred at a younger age compared with inland agriculturalists. However, these data cannot be entirely explained by the influence of physical activities related to lifestyle; as discussed in Chapter two (section 2.2.4), many other factors would have also been involved in its occurrence.

With regard to the correlation between OA and age at death (Tables 39 – 40), this study showed that, according to total true prevalence rates, OA increased steadily with increasing age in both coastal and inland populations. This pattern was particularly evident across the three age categories of inland agriculturalists and for all individual joints. Coastal fishers also showed an increase in prevalence of the condition from young to middle adulthood followed by a decrease in the old adult age category. This patterning was probably due to a reduction in the number of individuals and joints available for analysis within this age group rather than, as suggested earlier, the result of decrease in life expectancy of this group (Alfonso *et al*., 2007). These findings are consistent with the data obtained for enthesophytes (Tables 30 – 31) and with osteometric analysis performed on upper and lower limbs robusticity among inland agriculturalists (Table 63). Furthermore, in line with other bioarchaeological data (Bridges, 1992; Jurmain and Kilgore, 1995; Groves, 2006; Alves Cardoso, 2008) and the clinical studies of Jones *et al.* (2002), Solovieva *et al*. (2005), and Andrianakos *et al.* (2006), OA was positively correlated with age.

In summary, the hypothesis that ageing increases the likelihood of acquiring OA would give strength to the idea suggested earlier, that if the condition affects men and women as they grow old regardless of the professions or physical activities they practised, these variables are strong determinant factors that should not be underestimated.

6.2.4 Osteoarthritis according to laterality

The analysis of OA according to laterality showed no particular side dominance for any of the upper and lower limb joints for both coastal fishers and inland agriculturalists (Tables 41 – 42), thus suggesting a symmetrical distribution of the condition. The results obtained for enthesophytes (Tables 32 – 33) and os acromiale (Table 49) were consistent with these findings.

In the clinical field, the analysis of bilateral involvement of upper and lower OA has seldom been addressed. A few exceptions are the studies of Mahendranath (2004), Solovieva *et al.* (2005) and Rossignol *et al.* (2005) with the hand joints. Whereas Mahendranath (2004) reported that OA was prevalent in the left hand and wrist of string instrumentalists from India; Rossignol *et al.* (2005) found a high prevalence of bilateral involvement for OA in the hands of a group of French patients, and Solovieva *et al.* (2005) observed more OA in the non-dominant hand (distal inter-phalangeal joints) of teachers and dentists from Finland. Future analysis in which the bilateral involvement of OA is considered will certainly provide a clearer pattern of the distribution of OA according to bilateralism.

In bioarchaeology, it has been suggested that the pattern of OA according to laterality in prehistoric populations is linked to the dominant use of one arm over the other and therefore the upper limb joints should indicate more bilateral asymmetry because most humans are right-handed (Bridges, 1992). Bridges reviewed the published bioarchaeological data on OA and found that the joints of the upper limbs (shoulder and elbow) presented more OA on the right side than on the left side. This premise was supported by data obtained here for the inland agriculturalists (Table 42), but were supported only partially by data from the coastal fishers (Table 41), as only the elbow joint was more affected on the right side than on the left. On the other hand, analysis of the relationship between OA and laterality was not supported statistically. A number of other bioarchaeological studies (Merbs, 1983; Jurmain, 1990; Waldron, 1997) have also supported the premise that the right joints of the upper limbs are more affected than those from the left; however the significance of these results has been seldom tested. Therefore, the premise that upper limb asymmetry is linked to the differential use of the arms is not entirely demonstrated.

With regard to OA of the lower limbs, Bridges (1992) observed that there is more variation in patterning of left and right side involvement and the data obtained in this study followed this trend; no consistent prevalence rate was found among coastal and inland agriculturalists. Clinical studies on uni- or bilateral involvement of the lower limbs are rare and those presenting evidence for the upper limbs have shown, as summarised above, mixed results.

6.3 Spondylolysis

6.3.1 Spondylolysis according to vertebra

In line with clinical studies (Ruiz-Cotorro *et al*., 2006; Gregory *et al*., 2007) and bioarchaeological studies (Arriaza, 1997; Merbs, 2002b; Fibiger and Knüsel, 2005) the fifth lumbar vertebra was the vertebra most commonly affected by spondylolysis in both coastal and inland populations (Table 43). Only one example of multiple involvement was found in both skeletal samples, and this was in a coastal male affected in L4 and L5 (Table 43). Reports on multiple involvement are scarce in both clinical and bioarchaeological studies and, when they occur, they normally show variation in terms of the number and type of vertebrae affected as well as the type of separation (complete, incomplete, unilateral, or bilateral).

6.3.2 General comparisons between coastal and inland samples

General comparisons between both populations suggested that, on the basis of total true prevalence rates, coastal fishers were significantly more affected by spondylolysis than inland agriculturalists (Table 43). A similar trend was found for the results obtained for osteoarthritis (Table 34), and to some extent although not statistically significant os acromiale (Table 49) and osteochondritis dissecans (Table 55).

On the basis of these results and as discussed in previous sections, it could be suggested that the marine hunting and gathering subsistence economy practised by the Chinchorro people during the archaic period would have implied higher mechanical demands that lead not only to osteoarthritis of their upper and lower limb joints but also spondylolytic lesions in their lower backs. The agricultural way of life on the other hand, appeared according to these findings not to have resulted in such a negative effect on the joints and the spine.

Comparisons of other studies of a similar nature have not been carried out. Examples of spondylolytic cases affecting populations such as Eskimos where the subsistence economy was comparable to that of the Chinchorro people are abundant.

However, a search of Cohen and Armelagos (1984) and Cohen and Crane-Kramer (2007) did not find a single example of spondylolysis reported in the spine of Amerindian agriculturalists. Similarly, a search on the five year index (2003-2007) of the programme of the Paleopathology Association Annual and European meetings, and the seven year programme index (2001-2008) of the American Association of Physical Anthropology Annual meetings did not reveal any newly identified examples among these populations.

As discussed in Chapter two (section 2.3.6), the prevalence of spondylolysis among Alaskan and North American Eskimo ranges from 20% (6/30), to 60.5% (69/114) according to Merbs (1983, 2002a), Legge (2005) and Timm (2008). These crude prevalence rates are substantially higher than that found for the coastal fishers. For instance, a study conducted by Arriaza (1995a) on the spines of the Chinchorro people revealed that they were affected with a crude prevalence rate of 10% (5/51). Although this prevalence is low compared with those found for the Eskimos, it is likewise comparatively high compared with that found in the present study (4.0%, 11/271). Although sample size and the method of prevalence calculation might account for the differences observed in these studies, it should be borne in mind, that Eskimos are not only known for exhibiting the highest prevalence of spondylolysis among any groups of similar subsistence economy, but also the highest prevalence of the condition ever known for a human population.

In summary, the absence of studies reporting spondylolysis in Amerindians who practised an agricultural subsistence economy raises the question regarding the implication of these activities in the aetiology of the condition. It can also be speculated that the absence of information is only apparent and that evidence exists but in the form of unpublished laboratory reports. The finding of isolated examples of spondylolysis might not necessarily justify publication, thus diverting the attention of scholars to concentrate on other skeletal changes more commonly found among agricultural groups. Where examples are available, the information on how the prevalence rate was calculated is not always provided, thus making any comparative analysis difficult to perform. Anecdotal or isolated papers such as that of Ten Kate (1896) reporting spondylolysis in one mummy from the north-west of Argentina, or that of Bridges

(1989a) reporting on an affected individual among the Mississippian agriculturalists (USA), do not contribute to understanding the palaeoepidemiology of the condition among these populations. It is for this reason hoped that this study contributes to understanding the palaeoepidemiology of this condition among these groups.

6.3.3 Spondylolysis according to sex

The data for spondylolysis according to sex revealed that intra-group comparisons among coastal Chinchorros were statistically significant. On the basis of total true prevalence rates Chinchorro males were more affected by spondylolysis when compared with their female counterparts (Table 45). In line with these results, Chinchorro males were significantly more affected by enthesophytes (Table 26) and os acromiale (Table 51).

Bioarchaeologists have suggested that the differences observed in the prevalence of spondylolysis between the sexes in prehistoric populations are related to sexual division of labour (Bridges, 1989a; Merbs, 1996b; Arriaza, 1997; Molnar, 2006 and Timm, 2008). For instance, Merbs (1983) who worked with skeletons of Sadlermiut Eskimos suggested that these individuals engaged in activities in a peculiar posture that resulted in greater stress in the lower lumbar region. He suggested that both males and females spent long periods of the time stood, bent at the waist with legs kept straight whilst working with things on the ground. Males in particular would have also been likely to spend long hours seated in this position in kayaks. Heavy lifting, an activity well documented for Sadlermiut men was according to this author a very likely contributory factor to the shearing stresses. In line with this idea Timm (2008) compared the spines of two Inuit groups from Point Hope, Alaska, the Ipiutak, known for hunting caribou, seal, and walrus and the Tigarak, who hunted whales in addition to other large mammals. This author suggested that the high prevalence of spondylolysis in the spines of Ipiutak males 26% (5/19) compared with 9% (1/11) in females (1/11) and Tigarak males 50 % (21/42) compared with females 60% (30/50) was probably the result of both groups engaging in standing or sitting while bending at the waist with legs fully extended. The higher prevalence among Tigarak may be related to whale hunting activities in which the men towed the dead whale to shore and women dragged the meat to camp, thus predisposing both sexes to spondylolysis.

With regard to the particular case of the coastal Chinchorros, Arriaza (1995a, 1998) suggested that the higher prevalence of spondylolysis among males 18% (5/28) compared with females 0% (0/23) could indicate that the former group was subjected to highly mechanical demands or accidents such as hyperextension of the back while hunting and throwing harpoons and sticks with the atlatl or scrambling over and falling on the rocky areas of the Pacific coast.

As reviewed in Chapter two (section 2.3.4), clinical studies have suggested that there are two basic movements regarded as potentially predisposing to lysis of the pars interarticularis, repetitive spinal flexion and extension. The physical activities, sports and occupations that have been mentioned as requiring these movements are throwing sports, weight lifting, artistic gymnastics, rowing, wrestling, football, cricket and diving among others (Rossi and Dragoni, 1990; Soler and Calderón, 2000; Bono, 2004). Although weight lifting, throwing activities and rowing might have been performed by the Chinchorro people as daily activities, it would be difficult to confirm if the aetiology of spondylolysis in their cases was triggered by any of these. On the other hand, it should not be disregarded that spondylolysis has also been considered a hereditary condition, a congenital malformation and a developmental ossification failure of the laminae as indicated by a number of family and twin studies (Albanese and Pizzutillo, 1982; Young and Koning, 2003).
A spatial analysis of the distribution of individuals with spondylolysis buried at the cemeteries of Morro1 and Morro 1/6 (Figs 65-67) has shown mixed results. Assuming that biologically related individuals might have been buried together, it should be expected that those affected by spondylolysis would be located in proximity to their relatives. Information on each individual affected by spondylolysis within this group can be found in Table 44. Although there could be a suggestion of kinship or relationship between those buried in Morro 1 Tomb 27C4 and Tomb 27C5, there is not a clear pattern of a possible connection of spondylolysis and biologically related individuals in the remainder of cases. These cemeteries show a long period of occupancy and re-use of the funerary space and therefore numerous graves have been disturbed most-mortem, intercut, and truncated over the years (Focacci and Chacón,

1989), thus making it difficult to establish if individuals buried nearby belonged to familiar groups.

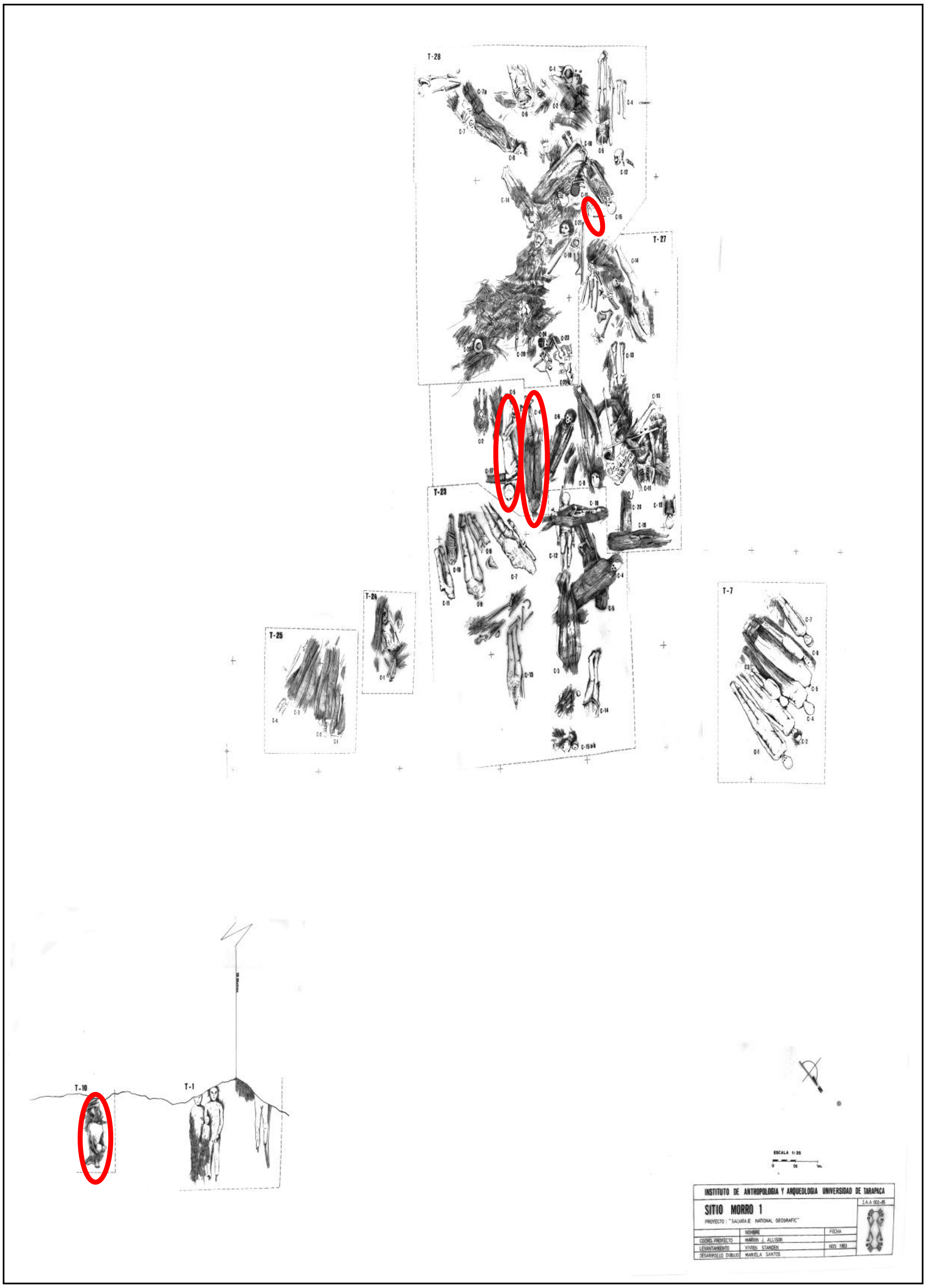


Figure 65: Distribution of individuals with spondylolysis in cemetery Morro 1. Archives of Museo Arqueológico San Miguel de Azapa

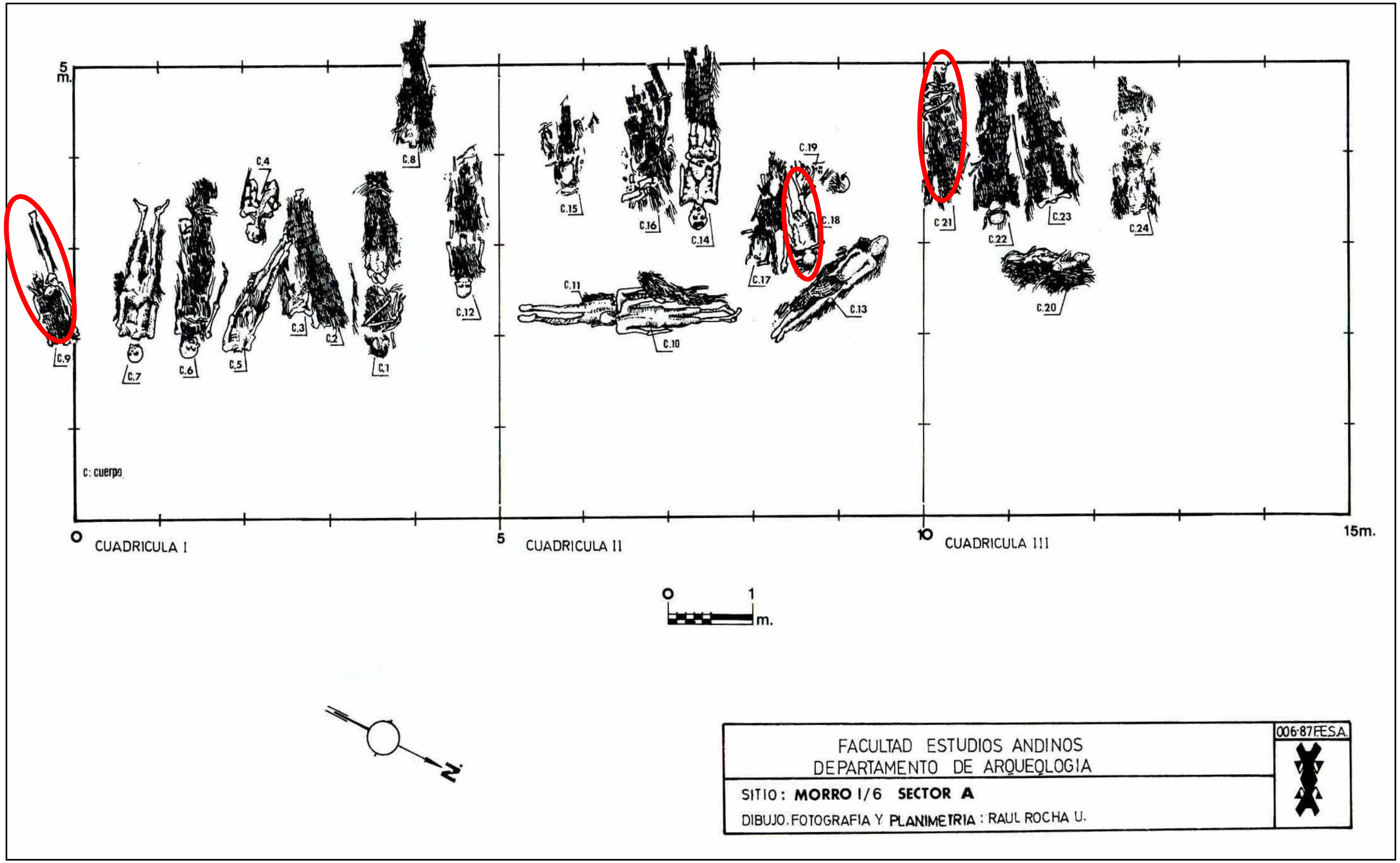


Figure 66: Distribution of individuals with spondylolysis in cemetery Morro 1/6. First excavation (sector A). Modified from Focacci and Chacón (1989)

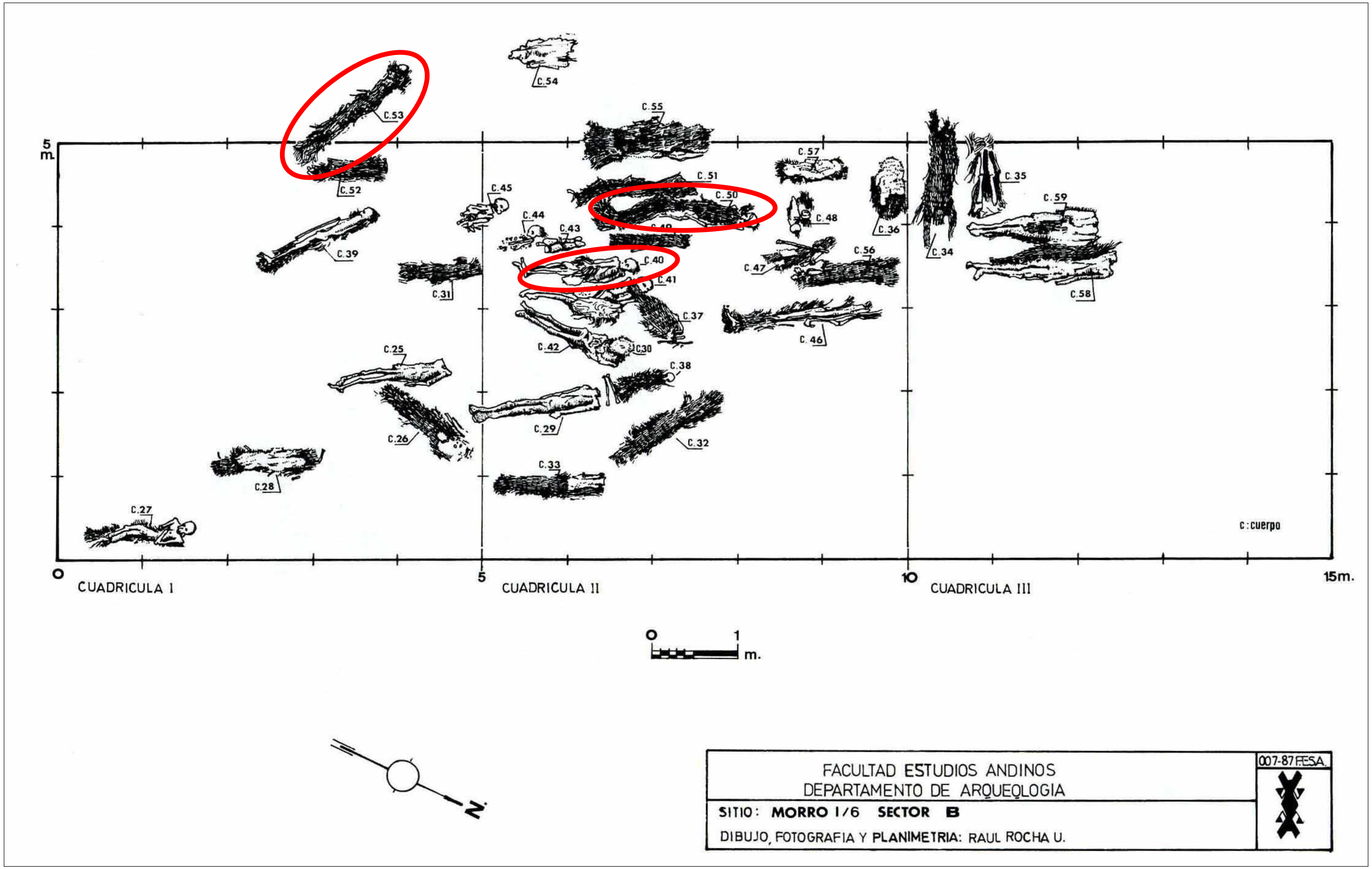


Figure 67: Distribution of individuals with spondylolysis in cemetery Morro 1/6. Second excavation (sector B). Modified from Focacci and Chacón (1989)

Furthermore, the fact that spondylolysis was found in nine male individuals and just one female, would give support the genetic-hereditary aetiology as if this were the case, the condition should have been found in a more balanced fashion between the sexes. On the contrary, the condition appeared to be a male landmark, thus emphasising the activity related nature of the condition and the sexual division of labour among individuals of this group.

As mentioned in previous sections of this discussion, and as reviewed in Chapter three (section 3.2.2), Standen (2003) suggested that on the basis of grave good analysis, allocation of tasks between the sexes was evident among Chinchorro people.
The results obtained for enthesophytes (Table 26), and os acromiale (Table 51) as well as the results obtained by Standen *et al.* (1995) with external auditory exostosis would also give strength to this idea. Assuming that spondylolysis represents an acquired stress fracture or is the consequence of "overuse syndrome", as reviewed in Chapter two (section 2.3.4), the results obtained in this study would suggest that Chinchorro men exposed their lower backs to greater stress compared to their female counterparts.

Intra-group comparisons among inland agriculturalists showed no sex-related variation in prevalence rates for spondylolysis (Table 46). Inland males (1.2%, 2/165) exhibited equivalent total true prevalence rates to that of the females (1.2%, 3/246). These results were consistent with those obtained for enthesophytes (Table 27), osteoarthritis (Table 36), and os acromiale (Table 52).

Inland agriculturalists have not been previously studied for the presence of spondylolysis and the bioarchaeological evidence of its presence according to sex affecting other agricultural Amerindian populations is, as summarised earlier (section 6.3.2 of this chapter), nonexistent. Bioarchaeologists have suggested that the differences observed in the prevalence of spondylolysis between the sexes in prehistoric populations are related to sexual division of labour (Bridges, 1989a; Merbs, 1996b; Arriaza, 1997; Molnar, 2006 and Timm, 2008). The absence of difference in the prevalence of spondylolysis between males and females would hence imply that both sexes participated in similar physical activities that placed equal stress on their spines. This hypothesis would give support to the results obtained by Standen *et al*. (1995) on external auditory exostosis that resulted in both sexes being equally affected. Alternatively it could be argued that both males and females participated in different tasks that lead independently to spondylolysis of their spines. Daily agricultural chores would have certainly involved the basic movements regarded as potentially predisposing to lysis of the pars interarticularis, repetitive spinal flexion and extension. However, if the aetiology of spondylolysis among these individuals was triggered by performing agricultural activities, it would be difficult to confirm as both sexes might have been involved in other non-agricultural activities that might have equally contributed to produce spondylolysis of their lower backs.

The analysis of grave goods among inland agriculturalists (Table 9) did not help in providing conclusive information regarding how the allocation of tasks between the sexes might have contributed to produce the condition. As suggested in other sections of this discussion, a sexual division of labour can be surmised from the grave goods content although a number of inconsistencies would raise questions regarding the reliability of this source of information. The fact that three "high status" individuals, Az71 Tomb 601, Az71 Tomb 605, and Az141 Tomb53 had spondylolysis would suggest that, providing the condition is activity-related, individuals of high rank were in line with non-elite individuals, involved in back breaking heavy duties. Furthermore, the low numbers of items that might suggest agricultural tasks did not allow further analysis of how this way of life might have contributed to produce the condition in both males and females. As discussed in Chapter three (section 3.3.1), as well as agriculture, inland agriculturalists practised other activities that might have equally contributed to produce the condition according to their sex and occupations.

With regards to a potential hereditary aetiology of the condition, unlike coastal Chinchorros, no map with the distribution of the individuals in the cemetery has been produced for inland agriculturalists. As mentioned in Chapter three (section 3.3.2) these cemeteries were excavated by Guillermo Focacci, Colagero Santoro and Iván Muñoz during the early 80's and resulted from salvage archaeology, and therefore due to time constraints no graphical documentation was produced. The lack of maps showing the spatial distribution of individuals affected has therefore not allowed any further analysis of a genetic-hereditary underlying connection of the condition. The fact that spondylolysis was found affecting both sexes equally as well as enthesophytes, osteoarthritis and os acromiale, would support the idea that the condition might have little connection with inheritance. On the contrary, the results found would give support to the traumatic-acquired aetiology.

In summary, although clinicians recognise that males are globally more affected by spondylolysis than females, they attribute this sex-related pattern to different reasons including pelvic inclination, BMI (body mass index) and lordotic angle (Sonne-Holm *et al*., 2007; Kalichman *et al*., 2009). Bioarchaeologists on the other hand, have suggested that the differences observed in the prevalence of spondylolysis between the sexes in prehistoric populations are related to sexual division of labour (Bridges, 1989a; Merbs, 1996b; Arriaza, 1997; Molnar, 2006; Timm, 2008). Both interpretations might be right and valid as long as these are understood in their own context, clinicians working with modern patients and bioarchaeologists with past populations.

6.3.4 Spondylolysis according to age at death

The results for spondylolysis according to age at death showed that, on the basis of total true prevalence rates (Tables 47 – 48), spondylolysis was present in all age groups for both coastal and inland groups. In line with these results, enthesophytes (Table 29), osteoarthritis (Table 38) and os acromiale (Tables 50 – 51) were also found affecting individuals of all age categories.

Furthermore, spondylolysis did not show an increase with age; in both coastal fishers and inland agriculturalists prevalence among young adults dropped towards middle adulthood and increased in the last age category.

In bioarchaeology, Merbs (1995) found that the prevalence rate for spondylolysis in ancient Canadian Eskimos was moderate in adolescents but nearly doubled in young adults. Merbs also suggested that a reduction in prevalence rates for spondylolysis from middle to old adulthood would be consistent with healing, particularly if the condition remained unilateral and severe spondylolisthesis did not occur. However, evidence of healing following a spondylolytic lesion was not present in any of the 271 lumbar vertebrae analysed in the Chinchorro sample, nor in the 411 of inland agriculturalists.

Mays (2006b) emphasised that if spondylolysis is acquired early during adult life but remains visible on the skeleton afterwards, then the adult group should show similar prevalence rates to the young group. The studies of Waldron (1991) and Mays (2006a) on British skeletons supported this idea; these studies were unable to demonstrate any increase in prevalence of spondylolysis with increasing age. In the clinical literature, the increase of spondylolysis with age appears to show a less clear pattern as Kalichman *et al.* (2009) found no difference in the prevalence of spondylolysis between patients of different age groups but Beutler *et al.* (2003) and Sonne-Holm *et al.* (2007) showed an increase of spondylolytic lesions with age.

In summary, from the study of spondylolysis and age, it is difficult to draw any conclusions because bioarchaeological studies addressing the association of this condition with age at death are rare and therefore any further interpretations or comparison are difficult. Furthermore, sample sizes in this study were not equally distributed among the three age categories, with few older adult individuals represented, thus making it difficult to understand any possible connection between the condition and age at death.

6.4 Os acromiale

6.4.1 General comparisons between coastal and inland samples

General comparisons between both populations suggested that, on the basis of total number of acromia analysed, coastal fishers were more affected by the condition than inland agriculturalists (Table 49), but these data were not statistically significant. Coastal Chinchorros were significantly more affected by osteoarthritis (Table 34), spondylolysis (Table 43) and to some extent (although not statistically significant) osteochondritis dissecans (Table 55).

On the basis of these results and as discussed in previous sections, it could be suggested that the marine hunting and gathering subsistence economy practised by the Chinchorro people during the archaic period would have implied higher mechanical demands that lead not only to os acromiale in their shoulders but also osteoarthritis of their upper and lower limb joints and spondylolytic lesions in their lower backs. The agricultural way of life on the other hand, appeared, according to these findings, not to have resulted in such a negative effect on the shoulders, the upper and lower limb joints and the spine.

In line with these results, as os acromiale is a condition that affects the shoulders, it would be expected that this pattern is present in enthesophytes and osteoarthritis of the shoulders. Furthermore, as os acromiale was more prevalent on the right acromia compared with the left (Table 49), it should also be expected that this trend be present in enthesophytes of the right shoulder and osteoarthritis of right shoulder. Comparisons of enthesophytes of the shoulder between coastal fishers and inland agriculturalists (Table 25) revealed that the former group was less affected than the latter, (49.6%, 113/228 compared with 52.6%, 308/586). This comparison was not statistically significant, but as discussed earlier in this chapter, enthesophytes were the only marker of occupational stress for which this group was more affected than coastal fishers and for which a sample bias could possibly be argued.

Contrary to this trend, osteoarthritis of the shoulder showed that coastal fishers were more affected than inland agriculturalists (32.5%, 51/157 compared with 24.7%, 54/344). In line with enthesophytes, this analysis was statistically not significant.
In summary, any association between enthesophytes and osteoarthritis of the shoulder was absent; however, a relationship between os acromiale and osteoarthritis of the shoulder could be suggested. Hence, giving support to the trauma theory in the aetiology of os acromiale. As discussed in Chapter two (section 2.4.4), osteoarthritis has been found occurring secondary to trauma. Pagnani *et al.* (2006) found degenerative changes at the acromio-clavicular joint in five of their clinical cases. Similar results were found by Edelson *et al.* (1993) and Sammarco (2000) who worked with skeletal remains and observed osteoarthritic changes on adjacent surfaces of the acromio-clavicular joint.

Secondly, with regards to laterality, coastal fishers were more affected by enthesophytes on the right shoulder (Table 32) but inland agriculturalists were more affected on the left shoulder (Table 54). The results for osteoarthritis showed that coastal fishers were more affected on the left shoulder (Table 41) whereas the opposite trend was found for inland agriculturalists (Table 42). In summary, the only consistent trend among the inland agriculturalists was between os acromiale of the right acromia and enthesophytes and osteoarthritis of the right shoulder. However, as none of these analyses were statistically significant, the finding will remain as a possible relationship only.

With regards to prevalences, as discussed in Chapter two (section 2.4.6), os acromiale is a condition rarely seen or not often reported by bioarchaeologists in the New World and therefore the evidence for it affecting other Native American groups is rare. As to the analysis of spondylolysis and osteochondritis dissecans, a search of Cohen and Armelagos (1984) and Cohen and Crane-Kramer (2007) did not find a single example of os acromiale. Similarly, a search of the five year index (2003-2007) of the programme of the Paleopathology Association Annual and European meetings, and the seven year programme index (2001-2008) of the American Association of Physical Anthropology Annual meeting did not reveal any new evidence reporting the presence of this condition in Native American populations.

The available information on os acromiale in Amerindian groups does not come from recent studies. Saunders (1978) worked on Eskimo-Aleuts and reported a very low crude prevalence rate for os acromiale (1.1%, 2/187) among these Arctic fishers and marine hunters. Similarly, Merbs (2009 pers. comm.) did not find any evidence when analysing many Inuit skeletons from Canada and Alaska. On the other hand, an old paper but one with a very thorough description analysing the condition in populations worldwide, is that of Vallois (1925). Here the presence of os acromiale among Eskimo skeletons was assessed and a crude prevalence rate of 33.3% (1/3) was found. When these prevalence rates are compared with those found for the Chinchorro people, disregarding the high prevalence found by Vallois, which was a result of the small sample analysed, it can be suggested that the Chinchorro people exhibited a relatively high prevalence of os acromiale when compared to these archaeological groups who had a similar subsistence economy.

Evidence of os acromiale in other Native American agricultural populations has not been reported and as with the discussion of spondylolysis (section 6.3.2) of this chapter this absence raises the question regarding the implication of these activities in the aetiology of the condition. Vallois (1925) suggested that os acromiale was an uncommon condition among Native American Indians compared with other populations but, as discussed in Chapter two (section 2.4.6), os acromiale is, in general, an infrequent condition, regardless of the origin or ethnicity of the population. The finding of isolated examples of os acromiale might not necessarily justify a publication, hence limiting the information available for analysis and discussion. It can also be speculated that affected individuals from archaeological sites do actually exist in the Amerindian literature, but are possibly forgotten in monographs and skeletal reports at various institutions. As with spondylolysis, this current study is unique.

Finally, according to clinical data, prevalence rates for os acromiale can range from between 1% and 15% according to Resnick (2002c). The results obtained in this study, in addition to the majority reviewed above, all fell within this range, suggesting that true and crude clinical prevalence rates appeared to be closer to those found for both coastal fishers and inland agriculturalists, although in general terms they tend to be higher. Samples sizes for archaeological groups and the number of patients seen tend to be larger than those observed in this study, which may account for some prevalence differences observed.

6.4.2 Os acromiale according to sex

It was not possible to determine with Chi-square analysis whether there were significant intra-group differences in the coastal Chinchorro between males and females for os acromiale because the females did not present any example of the condition (Table 51). Therefore, it could be assumed that males were probably significantly more affected (11.6%, 5/43) than females (0.0%, (0/43) although future studies involving a larger number of acromia might give a more definite answer. These results were consistent with those found for enthesophytes (Table 26), spondylolysis (Table 45) and to some extent osteoarthritis (Table 35) (although not statistically significant) where Chinchorro men were more affected than their female counterparts.

With regard to sex differences in the prevalence of os acromiale, clinicians have found that men tend to suffer from os acromiale more often than females (Sammarco, 2000; Gumina *et al*., 2003; Peckett *et al*., 2004; Boehm *et al*., 2005; Pagnani *et al*., 2006). Bioarchaeological studies have shown divided results with men more affected than females (Stirland, 1987, 2000; Case *et al*., 2006; Knüsel, 2007), and the contrary trend reported by Miles (1994) and Arabaolaza *et al*. (2007). Sex bias in the presence of os acromiale will tend to favour the trauma theory, according to Case *et al*. (2006), following the assumption that a sexual division of labour and sport preference exists for males and females.

Modern clinical studies have also suggested that os acromiale is commonly linked to sports and athletes engaged in “overhead” activities, or physical activity where repetitive overhead arm motions are combined with abduction and external rotation of the arm such as in volleyball, handball, tennis, badminton and swimming (Pećina and Bojanić, 1993; Pagnani *et al*., 2006; Demetracopoulos *et al*., 2006). In line with this idea, bioarchaeological studies have suggested a connection between os acromiale and archery and the use of projectiles in general (Stirland, 1987, 2000; Knüsel, 2007).

As summarised in Chapter three (section 3.2.1) the use of arrows, bows, atlatls and harpoons is consistent with “overhead” activities and with the Chinchorro archaeological record. However, it cannot be confirmed if these activities were directly responsible for the aetiology of this condition. Even in cases where os acromiale is known to have resulted from a particular type of overuse injury of the shoulder there are a number of factors including type of activity practised, its periodicity and repetitiveness as well as the nature of the load involved as they all potentially can play a role in manifesting the condition (Pećina and Bojanić, 1993; Pagnani *et al*., 2006; Demetracopoulos *et al*., 2006). As these vary according to each population, and would also tend to change over time, it would be difficult to pinpoint any specific activity or activities involved in triggering the condition among this group for which contemporary written documents or other non-archaeological information are absent.

Assuming that Chinchorro men were engaged in practising these activities that resulted in greater stress and trauma on their shoulders compared to Chinchorro females, would imply a sexual division of labour between the sexes. As discussed in section 6.3.3 of this chapter on spondylolysis, there is archaeological evidence to support the possible sexual division of labour amongst the Chinchorro people. The results obtained for enthesophytes (Table 26) and spondylolysis (Table 45) as well as the results obtained by Standen *et al.* (1995) with external auditory exostosis and Standen (2003) on the basis of grave good analysis would also give strength to this idea.

Furthermore, as discussed in Chapter two (section 2.4.4), os acromiale can occur in response to a genetic predisposition to non-fusion of the acromion. In line with the spatial analysis conducted on the distribution of spondylolysis among the individuals buried at the cemeteries of Morro1 and Morro 1/6 (Figs 65 - 67) the results for os acromiale (Fig 68) have provided little evidence to support a genetic predisposition for the condition. Assuming that biologically related individuals might have been buried together, it should be expected that those affected by this condition would be located in proximity to their relatives. However, as shown in Fig 68 the individuals affected by this condition (Table 50) were scattered in different areas of the cemetery with no particular trend that would point to familiar connection between the bodies. One of these (Morro 1 T19C-1) does not appear in the map of the cemetery because this skeleton was along with others excavated during 1983 when the systematical recording had not started.

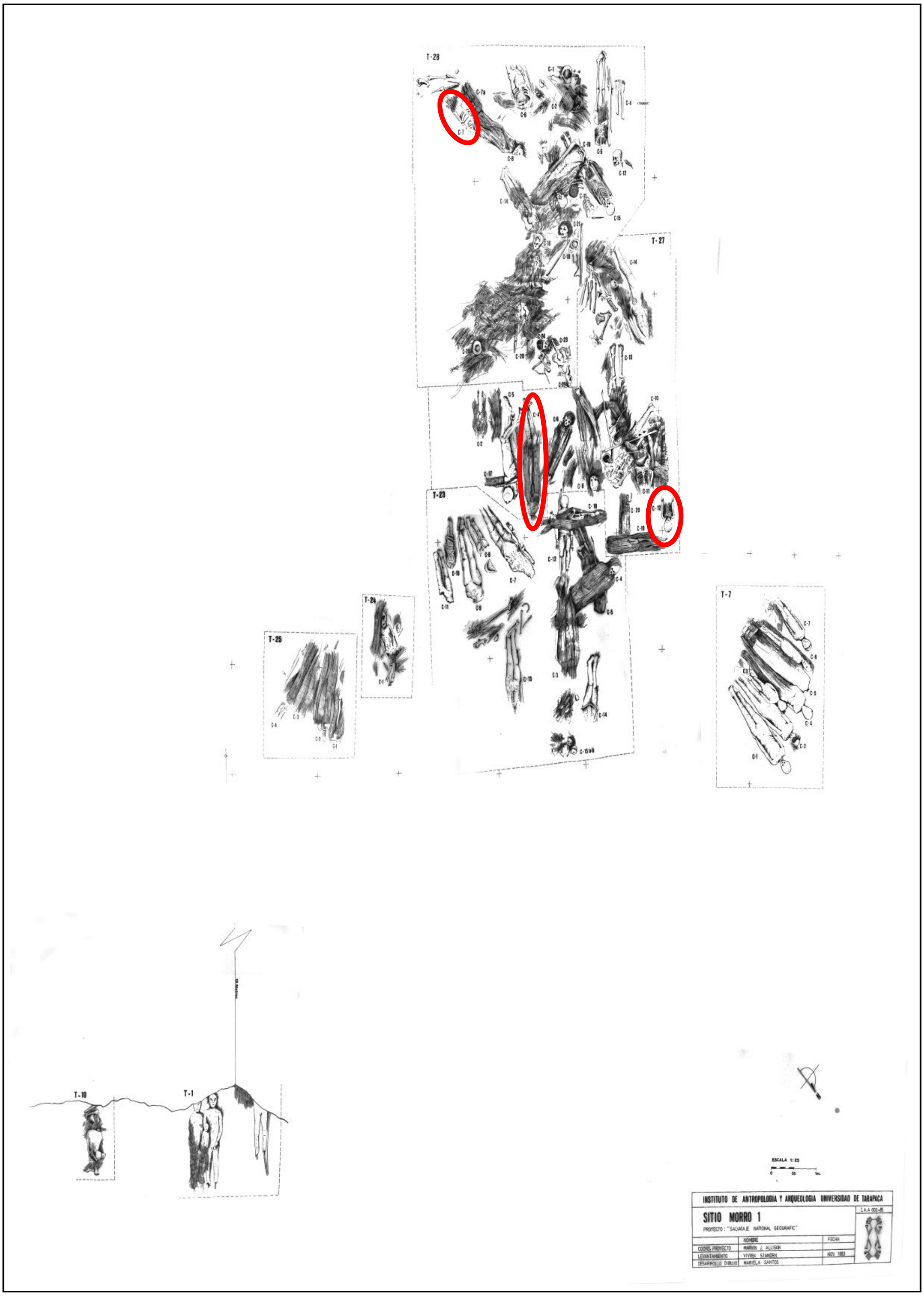


Figure 68: Distribution of individuals with os acromiale in cemetery Morro 1.

Furthermore, the fact that os acromiale was found among male individuals only, would give support to the activity related nature of the condition and the sexual division of labour among individuals of this group.

Intra-group comparison among the inland agriculturalists based on the total true prevalence rates, showed no statistical difference between the sexes (Table 52), thus mirroring the results obtained for enthesophytes (Table 27), osteoarthritis (Table 36) and spondylolysis (Table 46).

Inland agriculturalists have not been previously studied for the presence of os acromiale and the bioarchaeological evidence of its presence according to sex affecting other agricultural Amerindian populations is, as summarised earlier (section 6.4.1 of this chapter), nonexistent.

Bioarchaeologists have suggested a connection between os acromiale and archery and the use of projectiles in general (Stirland, 1987, 2000; Knüsel, 2007). As summarised in Chapter three (section 3.3.1) inland agriculturalists complemented their diet with hunting activities. The use of arrows, bows, harpoon heads and arrow heads have been documented in funerary contexts of inland agriculturalists (Muñoz, 2004) and these are consistent with “overhead” movements required to produce the condition according to the clinical literature (Pećina and Bojanić, 1993; Pagnani *et al.*, 2006; Demetracopoulos *et al.*, 2006). However, it cannot be confirmed if these activities were directly responsible for the aetiology of the condition among individuals of this group, particularly when according to the grave goods analysis (Table 9) none of the individuals associated with hunting equipment were affected by the condition. On the contrary, two female individuals (Az140 Tomb 100 and Az140 Tomb XPB), who were associated with the textile industry were affected by os acromiale. It would seem unlikely that performing activities related to the textile industry such as weaving and knitting can produce os acromiale, thus questioning once again, the reliability of the grave goods as data representing personal belongings.

Furthermore, as mentioned in Chapter three (section 3.3.2) no graphic documentation of the cemeteries of the inland agriculturalists was produced. The lack of maps showing the spatial distribution of individuals affected has therefore not allowed any further analysis of a genetic-hereditary underlying connection of the condition. The fact that os acromiale was found affecting both sexes equally as well as enthesophytes, osteoarthritis and spondylolysis, would support the idea that the condition might have little connection with inheritance. On the contrary, the results would give support to the traumatic-acquired aetiology and would suggest that both sexes probably exposed their shoulders to a similar amount of physical stress.

6.4.3 Os acromiale according to laterality

The analysis of os acromiale according to laterality showed no side dominance between right and left acromia for both coastal and inland populations (Table 49), thus suggesting a symmetrical distribution of the condition. These results were consistent with those obtained for enthesophytes according to laterality (Tables 32 – 33), and osteoarthritis and laterality (Tables 41 – 42). To some extent, the results obtained for osteochondritis dissecans among coastal fishers (Table 55) were also consistent with the above, but as this condition was represented by just one individual affected in both knee joints, it will not be used to support the other data.

Clinical studies such as that of Demetracopoulos *et al.* (2006) and Pagnani *et al*. (2006) have suggested that the dominant arm usually appears to be more affected than the non-dominant arm. Bioarchaeological studies have shown, on the other hand, mixed results. Right hand-side predominance has been reported by Vallois (1925) and Stirland (1996), and the contrary has been found by Miles (1994), Case *et al*. (2006), and Knüsel (2007). The discrepancies between bioarchaeological and clinical studies could be regarded as a problem of preservation of both scapulae of an individual rather than representing a real effect of side involvement, because it would be counterintuitive to find a left hand side bias when the majority of the world's population is right-handed. If laterality is connected to arm dominance, it could be suggested that Chinchorro men and inland agriculturalists were populations predominantly right-handed but as these findings were not supported statistically; it is hoped that future studies involving a larger sample of acromia will provide a clear pattern of the lateral involvement of os acromiale.

6.4.4 Os acromiale according to age at death

The data for os acromiale according to age at death showed that, on the basis of total true prevalence rates (Tables 53 – 54), the condition was present in all but old adult individuals for both costal fishers and inland agriculturalists. Furthermore, there appeared to be an increase in os acromiale only from young to middle adult age. These results were consistent with the data obtained for enthesophytes (Table 29) and osteoarthritis (Table 38) according to age.

The relationship between os acromiale and age has not been fully explored by clinicians, probably because their focus of attention is the treatment of the condition. A number of clinical studies, however, have reported the age at which the patient presented with shoulder pain. For instance, the average reported age of patients with os acromiale ranged from 17 to 75 years, with an average age of 50 (Park *et al.*, 1994; Peckett *et al.*, 2004; Boehm *et al.*, 2005 and Pagnani *et al.*, 2006). If os acromiale is not an age-related condition and therefore it can take place at any time in a person's life, then, as explained in Chapter two (section 2.4.4), its aetiology is more likely to represent a traumatic incident resulting from mechanical stress rather than a genetic predisposition. The absence of any particular distribution of the condition among the skeletons buried at the cemetery of Morro 1 (Fig 6.4) would give support to this idea.

Furthermore, the absence of examples in the old adult age category for both groups may be related to a decrease in the number of acromia available for study in this age group. It should also be considered that very few individuals from these archaeological populations would have lived as long as patients do today to manifest the condition at an old age.

Bioarchaeological studies addressing the age-related association of os acromiale are also very rare. In fact, none of the studies reviewed in Chapter two (section 2.4.6) have produced this information. However, it is usually the norm to find studies where the age of the individuals affected by the condition is provided but not the age-related nature of it. Merbs (1996a) suggested that assessing the onset age for spondylolysis is a difficult task to pursue because, in bioarchaeology, the age at death of the individual would normally be used as the onset age of the condition. To some extent, this is probably what occurs with os acromiale, which in turn would contribute to bias in the age-related analysis of the condition.

6.5 Osteochondritis dissecans

6.5.1 General comparisons between coastal and inland samples

Only one person was, affected by this condition from both coastal fishers and inland groups (Table 55). The individual in question (Morro1/5 TombTXVII) belonged to a Chinchorro individual who exhibited bony lesions compatible with osteochondritis dissecans in both medial femoral condyles. As the condition was absent among inland agriculturalists, no further comparative analysis between the samples was possible.

On the basis of the results obtained with other markers of occupational stress analysed in this study such as osteoarthritis (Table 34) and spondylolysis (Table 43) and to some extent (although not statistically significant) os acromiale (Table 49) there could be a suggestion that archaic coastal Chinchorros were exposed to higher mechanical demands compared with later agricultural groups. These lead not only to osteochondritis dissecans of the knee, but also osteoarthritis of their upper and lower limb joints, os acromiale in their shoulders, and spondylolytic lesions in their lower backs. The agricultural way of life on the other hand, appeared according to these findings not to have resulted in such a negative effect. However this assumption will be difficult to confirm unless future studies involving more skeletal samples are conducted.

In line with this idea, the comparison between both skeletal samples on the basis of the results obtained for enthesophytes of the knee showed that coastal fishers were less affected by this condition on this area (61.5%, 260/423) compared with inland agriculturalists (73.9%, 600/812). These results are not surprising since as discussed in previous sections the latter group exhibited considerably more enthesophytes available for observation and study than coastal fishers.

The comparison between osteoarthritis of the knee and osteochondritis dissecans, showed in line with the above example, that coastal fishers were less affected (25.8%, 55/213) compared with inland agriculturalists (26.2%, 78/298). The absence of association between both conditions is surprising, particularly when as discussed in Chapter two (section 2.2.4), osteoarthritis can occur secondarily to trauma. Taking into account the traumatic aetiology of the condition, a link between both conditions should be expected. In fact, long term follow up studies have shown that OD can lead to OA later in life (O'Farrell and Costello, 1982; Bauer *et al.*, 1987; Twyman *et al.*, 1991; Uematsu *et al.*, 2005). In the particular case of individual Morro1/5 TombTXVII both femoral condyles in their posterior aspects were affected by osteoarthritis but as the condition was not located adjacent to the osteochrondic lesions, but over the main weight bearing area of the femur, the direct link between the two cannot be confirmed.

As to the analysis of spondylolysis and os acromiale, a search of Cohen and Armelagos (1984) and Cohen and Crane-Kramer (2007) did not find a single example of osteochondritis dissecans. Similarly, a search on the five year index (2003-2007) of the programme of the Paleopathology Association Annual and European meetings, and the seven year programme index (2001-2008) of the American Association of Physical Anthropology Annual meetings did not reveal any newly identified examples reporting the presence of this condition in Native American populations. On the other hand, numerous examples (Wells, 1974; Stirland, 1991, 1996, Harman, 1998; Roberts and Cox, 2003; Brickley, 2006; Coughlan and Holst, 2007 and Arabaolaza *et al*., 2007) reporting isolated or anecdotal cases of osteochondritis dissecans of the knee have been published in the literature of European bioarchaeological populations. This phenomenon raises questions regarding whether osteochondritis dissecans is a rare condition among Amerindians or the absence of evidence is because the condition remained largely neglected or unrecognised by the scholars of this part of the world.

Finally, the data obtained in the current study indicated that two knee joints were affected by osteochondritis dissecans from a total of 314 knee joints available for study from both coastal and inland populations, thus giving a prevalence rate of 0.6% (2/314). In the bioarchaeological literature the only available comparative large scale study comes from a paper presented at the American Association of Physical Anthropologists in 1997 by Juliet Rogers. The author analysed 718 femora belonging to three Amerindian groups, the Chumash, Arikara and Indians from Virginia (USA) and found the condition to be present in 20 knees. True prevalence rates derived from this evidence suggested that 2.8% of these populations suffered from osteochondritis dissecans of the knee. This is considerably higher compared to that obtained in the present study; and also higher compared with the results obtained by Widuchowski *et al.* (2007) with Polish patients (1.3%, 332/25,124). Regrettably, essential information was not provided by these authors, such as the bone affected by the condition (i.e. femoral condyles, tibial plateau or patella), the sex and age distribution of those affected, laterality and how the prevalence was calculated, thus making difficult to compare them directly.

To summarise, the case found in the present study among the coastal Archaic Chinchorro, probably represents the first reported for an individual of the Southern Hemisphere and perhaps the oldest known on the continent (Kothari *et al*., 2009).

6.5.2 Osteochondritis dissecans according to sex

The only person affected by this osteochondritis dissecans among coastal fishers (Morro1/5 TombTXVII) was a female individual (Table 55).

As reviewed in Chapter two (sections 2.5.5 and 2.5.7) males are normally more affected than females by osteochondritis of the knee in both clinical (Jaberi, 2002; Uematsu *et al*., 2005; Widuchowski *et al*., 2007) and bioarchaeological studies (Stirland, 1996; Loveland *et al*., 1984). According to Ming *et al.* (2004) the reason behind the sex differentiation is because men are more actively involved in sport which, in turn, would imply an activity-related aetiology for the condition and a sexual division of labour among the sexes.

In bioarchaeology, osteochondritis of the knee has been linked with agricultural activities (Loveland *et al.*, 1984) and military activities (Knüsel, 2000:116), and also as discussed in Chapter two (sections 2.5.5 and 2.5.7), with movements involving hyperflexion of the knees while kneeling or squatting (Rogers, 1997). Clinicians on the other hand, have suggested that condition is linked with rotational forces taking place on a fixed weight-bearing knee (Resnick and Goergen, 2002).

Regardless of the activity or movement that may have elicited the lesion in the knees of Morro1/5 TombTXVII, if the activity-related premise is true, as supported by experimental and biomechanical studies (Tomatsu *et al*., 1992; Athanasiou *et al.*, 1995), it would be difficult to suggest that Chinchorro women were involved in physical activities that placed greater stress on their knees compared with their male counterparts, especially when only one example was found representing the condition and when the results obtained for enthesophytes (Table 26), spondylolysis (Table 45) and to an extent (although not statistically significant) osteoarthritis (Table 35) and os acromiale (Table 51) have shown the contrary. On the other hand, it could be suggested that the condition in Morro1/5 TombTXVII resulted from a single random traumatic event rather than being connected with repetitive microtrauma or with specific activities practised by Chinchorro females. In fact, patients seen by Jaberi (2002) and Widuchowski *et al.* (2007) presented with osteochondritis dissecans as the result of a single traumatic episode such as vehicular accident, falling down or knee twisting.

In summary, if Chinchorro females were at particular risk of osteochondritis dissecans because of specific activities or movement they practised it will remain unknown. Future studies in which more Chinchorro skeletons from both sexes are analysed will probably point to a more clear direction and hopefully help understand the results obtained with this study.

6.5.3 Osteochondritis dissecans according to age at death

As summarised in Chapter five (section 5.6), the skeleton of Morro1/5 TombTXVII was that of a middle adult female (35-49 years) according to the age categories of Buikstra and Ubelaker (1994).

With regard to age, osteochondritis dissecans is clinically known for being a condition of the immature skeleton. Its onset age ranges between 10 and 25 years, thus affecting paediatric, adolescent and young adult patients (Apley and Solomon, 1993; Jaberi, 2002; Ming *et al*., 2004; Brownlow *et al*., 2006). In line with this evidence, the example found in the present study has shown that the condition probably occurred during early adulthood, as suggested by the morphological analysis of the three loose bodies recovered. The right loose body was rounded, probably as a consequence of rolling free inside the joint space, suggesting that the condition developed many years before her death. The other two loose bodies of the left knee were slightly more asymmetric and had small spicules of bone suggesting a more recent development (Figs 61- 62). These were very remarkable features, as in patients with osteochondritis of the knee the loose bodies are rarely well rounded and remodelled, probably because the patient's symptoms makes them visit a physician for surgical intervention at an early age (Kothari *et al*., 2009). This evidence would therefore demonstrate the natural history of untreated osteochondritis dissecans that probably developed many years before Morro1/5 TombTXVII reached maturity, and probably remained active until her death.

In the bioarchaeological field, no attempt has been made to try to establish the onset age for osteochondritis dissecans in skeletal remains affected by the condition because only in a very few examples are the loose bodies preserved.

6.6 Osteometric analysis

The discussion for osteometric analysis is organised as follows. Firstly, general intra-group and inter-group comparisons between both samples are presented according to each index analysed. Secondly, metrical analysis is discussed according to sex and comparisons are also presented at the intra-group and inter-group level. Lastly, the condition is discussed according to age at death but only at the intra-group level. A brief summary is presented at the end of each section reviewing the patterns observed.

6.6.1 General comparisons between coastal and inland samples

Intra-group comparisons of laterality (Table 56) showed that the right humeri of coastal Chinchorros were significantly more robust than the left. These results are supported by a number of studies that report consistently asymmetrical upper limbs among hunter-gatherers (Merbs, 1983; Ruff *et al.*, 1984; Bridges, 1989b). On the other hand, inland agriculturalists showed no side robusticity dominance. The marked absence of asymmetry of the upper limb bones in settled societies such as inland agriculturalists has been interpreted by Bridges (1989b) and Wanner *et al.* (2007) as resulting from using both arms equally in activities involving food processing.

The results obtained from the MOS analysed here suggested that both groups were symmetrically affected in their upper limbs (shoulders and elbows) by enthesophytes, osteoarthritis (Tables 32 - 33, 41 - 42) and os acromiale (Table 49). The osteometric data were therefore consistent with those found for the inland group but inconsistent with those found for the coastal Chinchorro. Merbs (1983) suggested that the dominance pattern of the arms should be expected to reflect patterns of degenerative or other traumatic pathology. On the other hand, Ruff (1992) suggested that changes observed in bone geometry will not necessarily correlate with frequencies of osteoarthritis because even moderate workloads can potentially lead to diaphyseal changes without leading immediately to the development of osteoarthritis.

Lower limb robusticity also showed significant asymmetries among the coastal fishers but no bilateral effect among inland agriculturalists. The results obtained for the analysis of lower limb enthesophytes and osteoarthritis (hip, knee and ankle) revealed no significant results among both groups (Tables 32-33, 41-42). These results were again consistent with those obtained for the inland group but inconsistent with those found for coastal fishers.

The reason for this inconsistency can also be interpreted, as Ruff (1992) suggested earlier, that changes observed in bone geometry will not necessarily correlate with concomitant development of osteoarthritis or other skeletal markers. However, Čuk *et al.* (2001) and Auerbach and Ruff (2006) suggested that right handed people who have more robust right arms tend to have stronger left legs. The former authors observed that whereas about 90% of humans are mainly right-handed, the reverse trend (people with stronger left legs) is also found but this is less marked (55% to 75%). The reason behind this particular pattern is related to the differential role that the right and left femur play in ambulatory activities. Čuk *et al.* (2001) and Auerbach and Ruff (2006) suggested that the dominant or preferred leg, which is usually the right and the one used to lead in kicking or stepping, does not seems to be exposed to the high mechanical loads of the non-dominant leg, which is involved in posture and providing a stabilising support for the actions of the preferred leg. Thus, the increased robusticity in the left leg compared to the right, as observed among the Chinchorro people, could be explained as an example of "transverse" or "crossed" asymmetry.

With regard to the platymeric index, inland agriculturalists showed significant side differences in femoral subtrochanteric morphology although this trend was not seen among the coastal Chinchorro. Low platymeric index values are linked to more mechanically stressed bones (Larsen, 1997), thus suggesting differences in mechanical loads between the right and left femora. The degree of asymmetrical morphology is in long bones dependent on the forces exerted upon them. Čuk *et al.* (2001), however, as discussed in Chapter two (section 2.6.1), suggest that this could also be attributed to a number of hidden genetic, hormonal or nutritional factors. No asymmetry was observed among both groups for the tibial platycnemic index, thus suggesting that the degree of mediolateral flatness of this bone was similar in both groups and that they probably placed similar workloads on these bones.

Inter-group comparisons between coastal fishers and inland agriculturalists revealed no significant (R+L) differences in the humeral robusticity index (Table 57). If as suggested by Ruff *et al.* (1993), Knüsel (2000) and Stock and Shaw (2007), robusticity is accepted to be strongly related to physical activity, it could be surmised that, despite the differences in daily physical activities, occupations and subsistence economy practised by both groups, these demanded a similar amount of strength in their arms.

In line with these results, the comparison of upper limb enthesophytes (shoulder and elbow) between both groups did not reveal significant differences (Table 25). Both right and left acromia of both populations were similarly affected by os acromiale (Table 49). With regards to osteoarthritis of the upper limbs, the only statistical difference between coastal fishers and inland agriculturalists was found in the elbow joint, where the former group was more affected than the latter. The shoulder joint, on the other hand, followed the above pattern with no difference between populations.

The femoral robusticity index (Table 57) also showed, in line with the humeral robusticity, absence of (R+L) differences between both populations. Both enthesophytes and osteoarthritis of the lower limb followed this trend (Tables 24, 33). The only exception was observed in the entheseal areas of the knee, where inland agriculturalists were significantly more affected than coastal fishers (73.9%, 600/812 compared with 61.5%, 260/423).

In summary, equally robust humeri and femora were in general terms associated with equal expression of other MOS, thus suggesting that regardless of the subsistence economy practised by these populations, both right and left arms and legs sustained equal mechanical stress.

With regard to the femoral platymeric index (Table 57), comparisons between both groups suggested that coastal fishers presented stronger (R+L) lower limbs (index mean 79.7 compared with 82.8, $p<0.001$), thus implying they performed more mechanically demanding tasks using their legs than inland agriculturalists. In line with studies carried out with other Amerindian populations, Larsen (1984) and Ruff *et al*. (1984) suggested that with the shift to agricultural intensification a decrease in femoral dimensions would indicate less mechanical stress and more sedentary behaviour.

The tibial platycnemic index showed lower (R+L) mean values among inland agriculturalists (Table 56), contradicting the trend observed for the femoral platymeric index. Hence, data for both platymeric and platycnemic indices followed opposite directions, thus questioning the reliability of this information, and particularly the value of the platycnemic index. Normal variation in the location of the nutrient foramen on the tibia, as observed in the large disparity between minimum and maximum values, could have accounted for the variations observed and also for introducing background "noise" and producing inconsistencies within and between groups. Andermann (1976) questioned the value of this index precisely because it is measured at the nutrient foramen rather than at a fixed point. As mentioned in Chapter four (section 4.7.2), numerous tibiae had to be taken out of the current analysis due to the foramen was not visible.

In summary, general comparisons between both groups indicated a number of trends. Firstly, coastal fishers appeared to be more asymmetrical in their upper and lower limbs and these results are consistent with others studies carried out with populations practising a similar subsistence economy to those studied here. Secondly, although not always statistically significant, these data showed a slight but evident decline in humeral and femoral robusticity with time from archaic Chinchorro populations to later agriculturalists. A number of studies involving external long bone dimensions and cross-sectional geometry have found a similar decline in humeral and femoral robusticity with the arrival of agriculture in the New World, thus suggesting a decrease in mechanical demand with increasing sedentism (Larsen, 1981, 1984; Ruff *et al*., 1984; Larsen and Ruff, 1991, 1994; Larsen *et al*., 2007). Ruff *et al.* (1993) and Fischman (1995) observed a similar pattern but on a much larger temporal scale when working with skeletal remains belonging to the genus *Homo*. According to Fischman (1995) the primary cause of a decrease in humeral and femoral robusticity is due to a decrease in mechanical loading rather than a response to genetic factors.

Although the coastal Chinchorros were not a society of hunter-gatherers, but a semi-sedentary population (Arriaza, 1995a), the temporal decline in robusticity is evident even during the nearly 3000 years that separated both populations. If this phenomenon is connected with a decrease in mechanical demand and workload it could be suggested that the physical demands imposed on the upper limb by volitional activities, and those imposed on the lower limb by locomotion, involved less mechanical strength with the progression of time. However, a number of other variables, including intensity and duration of activities as well as diet or disease, could have also played a role.

6.6.2 Osteometric analysis according to sex

Intra-group sex comparisons among coastal fishers (Table 58) showed that with the exception of the humeral robusticity index, no significant difference was found between males and females for the remainder of the indices analysed (femoral robusticity, platymeric and platycnemic).

It has been suggested that in hunter-gatherer societies, differences in upper limb robusticity between the sexes are linked with different activities and the manipulation of weapons (Ruff, 1992, Stirland, 1993). A greater degree of asymmetry in humeral robusticity should be expected among males whose primary hunting weapon was a spear (Bridges, 1989b). Experimental studies involving the forces exerted on the upper limbs while thrusting a spear have supported this idea (Schmitt and Churchill, 2003).

Although the Chinchorro people were a semi-sedentary population (Arriaza, 1995a) the results found with the humeral robusticity index were consistent with different tasks being played between the sexes, particularly males and the use of weapons. Significant differences between Chinchorro males and females were also obtained with enthesophytes of the shoulder and elbow (Table 26), and os acromiale (Table 51). Males were significantly more affected than the females, thus suggesting their arms were exposed to higher mechanical loads and more physically demanding tasks.
The study of Standen (2003) on grave goods belonging to the Chinchorros would also give support to this idea as women were observed with artefacts associated with fishing

for small fishes (fishhooks, fishing weights and fishing lines) and men were associated with marine hunting tools (arrows and harpoons).

With regard to the lower limbs, several studies of cross-sectional geometric properties (Ruff *et al*., 1984; Ruff, 1987; Stock and Pfeiffer, 2004) have attributed a greater sexual dimorphism in lower limb robusticity in hunter-gatherers to greater daily mobility ranges among males. This idea was not supported by the results obtained here; on the contrary, the data for femoral robusticity index (Table 58) indicated no significant differences between the sexes. Similarly, the analysis of enthesophytes (Table 26) and osteoarthritis (Table 35) of the knee and ankle entheseal areas and joints showed no significant differences between the sexes. The data for the platymeric and platycnemic indices also supported the idea of equal mechanical stress between the sexes. These results would therefore point to similar degrees of mobility between the sexes and probably equal investment in daily work devoted to subsistence. Carlson *et al.* (2007) arrived at similar conclusions when they found an absence of lower limb sexual dimorphism in cross sectional properties in male and female Australian aborigines.

In summary, as reviewed in Chapter two (section 2.6.1); sex is well-documented to affect bone geometry, especially the upper limb robusticity (Ruff *et al.*, 1993). The absence of differences in lower limb robusticity between male and female Chinchorros would therefore indicate that sexual division of labour among these individuals was perhaps only present in tasks involving the upper limbs.

Intra-group sex comparisons among inland agriculturalists (Table 59) showed that in line with the results found for coastal Chinchorros, males presented more robust humeri than the females. Stock and Pfeiffer (2004) suggested that in settled societies the absence of marked asymmetry of upper limb bones, particularly among females, is a response to activities associated with food processing involving the use of both arms in grinding maize and other seeds with mortars and pestles. This assumption would be difficult to confirm, particularly when the results obtained for the analysis of grave goods (Table 9) did not provide conclusive results as to how activities involving the use of upper limbs were divided according to sex among these individuals. Furthermore, the fact that the agricultural males presented more robust arms did not follow the patterns observed for enthesophytes and osteoarthritis of the shoulder and elbow (Tables 26, 35), and os acromiale of the scapulae (Table 52) where both males and females were equally affected.

With regard to lower limb robusticity, Carlson *et al.* (2007) suggested that agricultural males and females are generally characterised by presenting a more similar mobility pattern since both sexes were presumably more sedentary overall. The results obtained for the femoral robusticity index and the platymeric index showed significant differences between the sexes suggesting that males exhibited more mechanically stressed and hypertrophic femora than females. As to the humeral robusticity index, these results contradicted those found for enthesophytes and osteoarthritis of the hip, knee and ankle (Tables 26, 35) with the only exception being enthesophytes of the knee by which inland males were more affected than the females.

Finally, the tibial platycnemic index was the only index that did not show sex-based difference between agricultural males and females. Contrary to the femoral platymeric index, the degree of medio-lateral flatness of the tibiae resulted from equal mechanical stress exerted on the bones of males and females.

In summary, one of the trends resulting from the intra-group sex analysis among inland agriculturalists is that inland males appeared to be more robust than females in both upper and lower limbs. This is contrary to what would be expected for a sedentary population. As suggested by Ruff (1992) geometric properties of long bones do not necessarily correlate with frequencies of other skeletal markers of activity, thus suggesting that in these particular cases the hypertrophy of the humeri and the femora did not result in further development of other MOS. This in turn would suggest that both skeletal indicators do not necessarily support one another in terms of aetiology.

Inter-group comparisons among females (Table 60) showed that both groups were equally robust in their upper limbs, suggesting that sex differences in laterality were only present in both groups when females were compared to their male counterparts. Comparisons with other MOS suggested no statistical differences between females for the presence of enthesophytes and osteoarthritis of the upper limbs (Tables 27, 36). In line with these results, os acromiale was also not significant between both groups (Fisher's exact=1.000, p>0.005). The only exception was found with the enthesophytes of the shoulder area where inland females were significantly more affected than the coastal females.

The data for the femoral robusticity index were consistent, with coastal females having significantly more robust femora compared to inland females. Marchi *et al*. (2006) suggested that terrain can have an effect on lower limb robusticity. If this were the case, this index should have been higher among inland females where the uneven terrain of the Azapa valley where these populations were settled could have had an effect on hypertrophy and robusticity. However, the significant decrease in lower limb robusticity from coastal to inland females is consistent with a temporal reduction in femoral robusticity observed by Larsen (1981, 1984) and Ruff *et al*. (1984) with the arrival of agriculture in the New World. Furthermore, the impact of nutritional status and systemic variables such as hormones could not be ruled out as potential contributory factors for the differences between females.

The results for the platymeric index showed that despite coastal females exhibiting more robust femora; inland agriculturalists were more mechanically stressed. The tibial platycnemic index showed no difference between these groups. General comparisons between coastal and inland samples (Table 57) as well as comparisons performed at the intra-group (Tables 58 - 59) and inter-group level (Table 60) according to sex revealed that the degree of medio-lateral flatness of this bone did not show any statistical differences between these groups. Thus, suggesting that equal mechanical stress was exerted in these weight bearing bones regardless of the physical activity or subsistence economy practised by early archaic or later agricultural populations.

Inter-group comparisons among males (Table 61) showed no significant differences for the humeral and femoral robusticity indices, suggesting that the upper and lower limbs of both groups were similarly hypertrophic. In line with these results, other MOS including enthesophytes, osteoarthritis and os acromiale affecting the shoulders and elbows (Tables 28, 37, 49) also showed no difference between males. Lower limb markers of activity were less consistent. No differences were found only for enthesophytes and osteoarthritis of the ankle joint, but statistically significant differences between the sexes were found for knee enthesophytes and for osteoarthritis of the hip.

The platymeric index showed lower mean values among coastal males and indicated a more mechanically stressed group compared with the inland men (Table 61). In line with the results obtained for the females (Table 60) the results were consistent with a slight but evident decline in the geometric properties of the long bones with the arrival of agriculture. Finally, the platycnemic index values did not show differences between the groups. As suggested earlier, equal mechanical stress between these groups could be hypothesised from the analysis of these weight bearing bones. However, their reliability as a source of population comparison can be questioned once again as a reliable osteometric tool because of the variation in the location of the nutrient foramen on the tibia, as suggested by Andermann (1976).

In summary, some of the trends observed in the inter-group comparisons among females and males are related to the absence of asymmetrical upper limb robusticity. This particular trend can be seen as resulting from equal mechanical demands and workload. Lower limb robusticity suggested differences in ambulatory workloads only among females, suggesting that different specific roles within the Chinchorro and inland groups, with the former more physically active and the latter more sedentary. Furthermore, the slight but evident temporal decline of upper and lower limb robusticity from coastal Chinchorros to inland agriculturalists should not be disregarded, despite a number of well known bone morphology influencing variables including diet and hormonal changes with age, as well as nutritional and inheritance influences.

6.6.3 Osteometric analysis according to age at death

As discussed in Chapter two (section 2.6.1), one of the best documented variables influencing changes in bone architecture is age. A number of clinical studies have shown that long-term sport participation is associated with an increase in bone mass and mineral density (Calbet *et al*., 2001; Vicente Rodriguez *et al*., 2005; Ducher *et al*., 2006), hence suggesting a temporal trend in bone hypertrophy during life.

Bioarchaeological studies addressing external bone dimensions according to age are rare. For instance, whereas Stirland (1993) found a small but definite trend for external dimensions of the humerus to increase with age for both right and left bones, Wanner *et al.* (2007) found opposite results. These authors found no significant age differences in the external diaphyseal geometric properties of the humerus, radius, femur and tibia in their skeletal sample from Yucatan, Mexico. The results obtained in this study for the coastal fishers showed that with the exception of only the femoral robusticity index (Table 62), the remaining indices did not exhibit any correlation with age. These findings could suggest that growing old among coastal fishers meant that the physical activities performed, to contribute to the subsistence economy of the group, increased significantly only in ambulatory activities. This increment was not seen in the humerus according to age and for this reason it could hypothesised that individuals from all age groups were equally involved in upper limb tasks or that the three age categories were simply not reliable enough to produce contrasting differences between the individuals.

The results obtained from enthesophytes and osteoarthritis (Tables 29, 38) revealed a strong correlation with age thus suggesting again that changes in external bone geometry do not necessarily go hand in hand with manifesting other skeletal markers of occupational stress.

Inland agriculturalists on the other hand, showed that increasing age was related with gaining further humeral and femoral robusticity (Table 63). These results were in line with those found for the femoral platymeric index implying an increase in mechanical stress with ageing. It could be suggested that larger dimensions of these bones resulted from the combined effect of lifestyle and terrain, given the hilly nature of the Azapa Valley where this population settled. Larger dimensions of these bones resulted in enthesophyte formation and osteoarthritis affliction (Tables 30, 39).

In summary, both populations manifested an increment in the prevalences of enthesophytes and osteoarthritis at similar entheseal areas and joints with ageing. Biomechanical stress, bone hypertrophy and robusticity did not follow a similar path in both coastal and inland populations despite suggestions of closely concordant results between both approaches (Ruff, 1992; Larsen *et al*., 2007). External bone dimensions, as well as enthesophytes and osteoarthritis, are all conditioned by a number of influencing factors that do not necessarily work in unison and that bioarchaeologists cannot always control. These include age at which the specific “detrimental” physical activity started and finished, the frequency and number of years practiced the type of loading and strain, the bone involved, and even other hidden genetic, hormonal and nutritional factors.

Chapter 7:

Conclusion

Chapter 7: Conclusion

The aim of this study was to compare the presence of purported activity-related skeletal changes in two prehistoric Amerindians populations from northern Chile. For this purpose a group of markers of occupational stress (MOS) were recorded, including enthesophytes, osteoarthritis, spondylolysis, os acromiale, and osteochondritis dissecans, along with external bone dimensions because they have been used by other scholars to analyse and compare patterns of activity in past populations.

The main important trends observed in this study are summarised as follows and refer to the aims and objectives set out in chapter one.

7.1 General trends seen for the MOS

On the basis of the MOS analysed in this study, it is suggested that the lifestyle of coastal populations during the 3rd millennium BC was more arduous, and physically demanding and detrimental to health, in comparison with inland populations settled in the Azapa valley of northern Chile during the 1st millennium AD. In line with this, it could also be suggested that the practise of marine resource hunting and gathering was more mechanically demanding and physically stressful for the Chinchorro people compared with a subsistence economy based on agriculture and farming practised by later inland populations. If these differences correlate to differences in levels of specific/general activity it is highly debatable because of the many aetiological factors that can cause the MOS. However, the results found in this study followed those obtained by a number of scholars involved in the study of physical activity and health in prehistoric Amerindian populations. These studies have suggested that there was a decrease in mechanical and occupational stress and a reduction in the prevalence of the MOS with the arrival of agriculture in the New World. Hence, the gradual transition towards a sedentary way of life and the reliance on food production did not lead to negative health consequences (in terms of these particular skeletal indicators) for these prehistoric populations.

The results of the analysis of enthesophytes and osteoarthritis did not correlate with each other. Enthesophytes were significantly more prevalent among inland agriculturalists and osteoarthritis had a higher prevalence among coastal fishers thus suggesting that in these particular examples, increased muscle strain was not directly associated with concomitant osteoarthritic changes. Therefore, it could be suggested that physical activity might not explain entirely the presence of these MOS and perhaps age and other aetiological factors were equally important determinants.

7.2 General trends seen for the MOS according to sex

With regard to the coastal Chinchorros, the most important trend to highlight is that males and females showed a marked difference in the presence and distribution of MOS. Chinchorro males in particular appeared to have been significantly affected by most of these skeletal markers compared to their female counterparts. Assuming that these markers represent levels of physical activity and mechanical stress, it could be hypothesised that Chinchorro males experienced a more physically demanding lifestyle. These findings might suggest that sexual division of labour among individuals of this population was a determinant social factor that led males and females to engage in occupations that placed different mechanical stress on their bodies.

Inland agriculturalists showed, on the other hand, an opposite trend to that of the coastal Chinchorros. Inland males and females appeared to show a consistent absence in difference in the patterning of MOS. Although the sexual division of labour among these populations has not been systematically explored, the results obtained in this study could suggest that males and females engaged in physical activities that resulted in similar mechanical stress. It could be hypothesised that these resulted from both sexes taking part in strenuous agricultural tasks. However, this assumption would be difficult to confirm particularly when the aetiology of these markers has been linked with multiple factors.

In summary, intra-group comparisons among males and females of coastal and inland populations were consistent with studies conducted on sexual division of labour among agricultural and pre-agricultural populations.

Inter-group sex comparisons revealed that with the exception of spondylolysis, males from both groups were similarly affected by MOS. Females on the other hand, displayed a varied pattern of MOS, suggesting a less consistent relationship to that observed between males. These results suggest that trends should be considered at the intra-group level and for each group separately. Assuming that these markers result from physical activity and occupation, these results would suggest that, regardless of the subsistence economy practised, men from both populations executed and performed the most demanding physical activities. Women on the other hand, would have changed their roles in society over time, from early Chinchorro to later inland agriculturalists, getting progressively more involved in the demanding way of life imposed by agriculture.

7.3 General trends for the MOS according to age at death

Coastal Chinchorros appeared to have been more affected at all age categories by enthesophytes, osteoarthritis, spondylolysis, and os acromiale when compared with inland agriculturalists. Hence, the lifestyle and occupations of archaic marine hunter and gatherers appeared to have been significantly more demanding at all age groups when compared with populations whose subsistence economy was based on agriculture.

Furthermore, the correlation tests for enthesophytes and osteoarthritis showed a steady increase in prevalence rates with age suggesting that if ageing increases the likelihood of acquiring these conditions in both men and women regardless of the professions or physical activities they practised, this variable is a strong determinant aetiological factor. Questions are consequently raised regarding their reliability as activity-related markers. On the other hand, the fact that enthesophytes and osteoarthritis were found affecting the entheseal areas and the joints of individuals as young as 19 years of age, would give strength to the activity-related aetiology at least among young adults. According to the clinical literature, the onset age of these conditions (osteoarthritis in particular) starts later in adult life. Thus, coastal Chinchorros appeared to have been exposed to higher mechanical stress at a younger age compared to inland agriculturalists suggesting that their active role in society started at a young age/early in life.

7.4 General trends for the MOS according to external osteometric analysis

Temporal trends in MOS according to external osteometric analysis revealed a decline in long bone humeral and femoral robusticity with time, supporting previous studies aimed at analysing temporal trends in robusticity. On the other hand, changes in bone geometry did not always follow the trends observed for the MOS thus suggesting that, at least for the skeletal remains analysed in this study, mechanical stress exerted in the upper and lower limbs did not necessarily lead to the development of noticeable muscle marker insertions, osteoarthritis of the joints or os acromiale of the scapulae.

7.5 Limitations

The major limitation encountered in this study was methodological. Lack of consensus for recording the MOS studied, and sometimes a lack of information provided as to how prevalence rates were calculated in other studies. This made comparative studies extremely difficult. In addition, as the diagnosis of some MOS in bioarchaeology is different to those used by clinicians then it was difficult to compare prevalence rates in clinical and bioarchaeological studies.

Secondly, along with this, the absence of published data regarding osteochondritis dissecans, os acromiale, and to some extent spondylolysis, affecting Native American populations, particularly from South America, was an important limitation for comparison of these data with those from other authors. The reasons for this absence is probably due to the fact that these MOS have not been systematically addressed by scholars from this part of the world or, where studies have been performed, they may have not been published.

Thirdly, although the degree of preservation of these skeletons was excellent, on the other hand approximately half of the individuals could not be assessed due to the presence of soft tissues. This reduced the number of skeletons available for analysis and in some cases led to sample sizes that were too small to be analysed statistically. That was the case with Coastal Chinchorros, particularly when the MOS were analysed according to age. The sample sizes were often too small to allow certain statistical tests to be performed.

7.6 Future work

Potential future work to be carried out with coastal Chinchorros and inland agriculturalists are related with the patterning of osteoarthritis. The remarkable preservation of these human skeletal remains has the potential for further detailed work on the analysis of hyaline cartilage degradation. The unique opportunity of being able to directly observe preserved hyaline cartilage attached to the bone presents an advantage that neither clinicians who diagnose osteoarthritis with radiographs nor bioarchaeologists who deal with dry bones have. These advantages can be summarised as follows:

- Identification of early manifestations of pathological changes
- Identification of subchondral bone response and reaction
- Identification of specific diachronic changes of the condition
- Identification of vulnerable areas prone to “wear and tear”, loading and degeneration within the hyaline cartilage and within specific joints

Future work beyond this study is needed on MOS. A number of suggestions were summarised in earlier chapters. Firstly, they pointed to the necessity of standardised methods to define, diagnose and record MOS in order to be able to produce data that is appropriate for interpopulational comparison. Secondly, the necessity of independent verification from controlled clinical studies for which aetiological aspects of the conditions are known and thirdly, a close interaction between clinicians and bioarchaeologists in order to produce more reliable interpretations and conclusions.

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Appendix

Site	Skeleton ID	Sex	Age	Costal tuberosity L	Lesser tubercle L	Greater tubercle L	Deltoid tuberosity L	Costal tuberosity R	Lesser tubercle R	Greater tubercle R	Deltoid tuberosity R	Medial epicondyle L	Lateral epicondyle L	Radial tuberosity L	Olecranon L	Ulnar tuberosity L	Medial epicondyle R	Lateral epicondyle R	Radial tuberosity R	Olecranon R	Ulnar tuberosity R	Ischial tuberosity L	Ischial tuberosity R	Lesser trochanter L	Greater trochanter L	Linea aspera L	Tibial tuberosity L	Soleal line L	Lesser trochanter R	Greater trochanter R	Linea aspera R	Tibial tuberosity R	Soleal line R	Calcaneal tuberosity L	Calcaneal tuberosity R
Morro 1	Tumba 3	F	O-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	Yes	N/A	N/A	N/A	N/A
Morro 1	Tumba 9	F	M-A	N/A	No	No	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 4	M	Y-A	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	N/A	N/A	N/A	Yes	Yes	Yes	N/A	No	Yes	N/A	N/A	N/A	No	N/A	N/A
Morro 1	Tumba 10A	M	Y-A	No	N/A	N/A	No	No	No	No	N/A	No	N/A	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes	No	No	No	Yes	Yes	No	Yes	No	No	Yes	No	Yes	N/A	N/A
Morro 1	Tumba 10B	F	M-A	N/A	Yes	N/A	N/A	Yes	No	N/A	N/A	N/A	Yes	Yes	No	N/A	No	N/A	Yes	N/A	No	Yes	N/A	N/A	Yes	Yes	N/A	No	Yes	N/A	Yes	N/A	No	N/A	N/A
Morro 1	Tumba 12	M	Y-A	No	N/A	N/A	N/A	No	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	No	No	No	Yes	No	No	No	No	No	N/A	N/A	No	No	No	N/A	No	N/A	N/A
Morro 1	Tumba 12B	F	M-A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	Yes	No	N/A	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 22 C5	F	Y-A	Yes	N/A	N/A	N/A	Yes	Yes	N/A	N/A	N/A	Yes	N/A	N/A	Yes	N/A	N/A	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 19 C1	M	Y-A	No	No	N/A	Yes	No	N/A	N/A	Yes	No	No	Yes	N/A	N/A	N/A	No	Yes	No	Yes	No	N/A	No	Yes	Yes	N/A	No	Yes	Yes	Yes	N/A	No	N/A	N/A
Morro 1	Tumba 28	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	No	No	Yes	N/A	Yes	Yes	No	Yes	N/A	Yes	N/A	No
Morro 1	Tumba 28 C11	M	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	No	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	No	Yes	Yes	N/A	N/A	N/A	N/A
Morro 1	Tumba 28 C15	F	M-A	Yes	N/A	N/A	Yes	Yes	No	No	N/A	No	No	Yes	No	Yes	No	N/A	Yes	N/A	N/A	N/A	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 23 C3	M	Y-A	Yes	No	N/A	N/A	Yes	No	N/A	Yes	N/A	N/A	Yes	N/A	Yes	N/A	N/A	N/A	N/A	N/A	No	No	N/A	N/A	Yes	N/A	Yes	No	Yes	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 15	F	Y-A	No	No	No	N/A	No	N/A	No	N/A	N/A	N/A	N/A	No	Yes	N/A	No	N/A	No	N/A	Yes	Yes	Yes	N/A	Yes	N/A	N/A	Yes	Yes	Yes	N/A	N/A	N/A	N/A
Morro 1	Tumba 28 C5	F	M-A	N/A	N/A	N/A	N/A	Yes	Yes	Yes	Yes	N/A	N/A	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 28 C28	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	Yes	No	Yes	N/A	Yes	Yes	Yes	Yes	N/A	No	N/A	N/A
Morro 1	Tumba 27 C11	M	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 27 C10	M	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	No	N/A	No	N/A	N/A
Morro 1	Tumba 27 C12	M	M-A	Yes	N/A	N/A	Yes	Yes	Yes	N/A	Yes	N/A	Yes	No	N/A	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	N/A	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 27 C8	F	O-A	No	N/A	N/A	Yes	N/A	N/A	N/A	Yes	No	No	N/A	N/A	N/A	No	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	N/A	Yes	No	Yes	N/A	N/A
Morro 1	Tumba 27 C13	F	M-A	Yes	Yes	N/A	Yes	N/A	Yes	N/A	Yes	Yes	Yes	No	Yes	Yes	N/A	Yes	No	N/A	Yes	Yes	Yes	N/A	N/A	Yes	N/A	Yes	N/A	Yes	Yes	N/A	Yes	N/A	Yes
Morro 1	Tumba 16 A	M	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	Yes	Yes	Yes	N/A	Yes	Yes	N/A	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 6	F	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A
Morro 1	Tumba 18 C3	M	M-A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	Yes	No	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 16 B	M	M-A	Yes	N/A	N/A	N/A	Yes	Yes	No	Yes	N/A	N/A	Yes	N/A	Yes	N/A	Yes	Yes	N/A	Yes	N/A	N/A	Yes	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix 1: Enthesophytes of coastal fishers

Site	Skeleton ID	Sex	Age	Costal tuberosity L	Lesser tubercle L	Greater tubercle L	Deltoid tuberosity L	Costal tuberosity R	Lesser tubercle R	Greater tubercle R	Deltoid tuberosity R	Medial epicondyle L	Lateral epicondyle L	Radial tuberosity L	Olecranon L	Ulnar tuberosity L	Medial epicondyle R	Lateral epicondyle R	Radial tuberosity R	Olecranon R	Ulnar tuberosity R	Ischial tuberosity L	Ischial tuberosity R	Lesser trochanter L	Greater trochanter L	Linea aspera L	Tibial tuberosity L	Soleal line L	Lesser trochanter R	Greater trochanter R	Linea aspera R	Tibial tuberosity R	Soleal line R	Calcaneal tuberosity L	Calcaneal tuberosity R
Morro 1	Tumba 23 C13	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	Yes	N/A	N/A
Morro 1	Tumba 23 C5	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	No	No	Yes	N/A	No	N/A	N/A
Morro 1	Tumba 8	F	Y-A	Yes	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	N/A	Yes	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 27 C5	M	Y-A	N/A	Yes	No	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	No	No	Yes	Yes	Yes	N/A	No	Yes	N/A	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 28 C10	M	Y-A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	Yes	No	N/A	Yes	Yes	N/A	N/A	N/A
Morro 1	Tumba 23 C12	F	Y-A	Yes	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	Yes	N/A	Yes	N/A	No	N/A	N/A
Morro 1	Tumba 27 C18	M	M-A	No	N/A	N/A	Yes	Yes	No	N/A	Yes	Yes	N/A	Yes	N/A	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Morro 1	Tumba 25 C3	M	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	No	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	No	Yes	N/A	No	N/A	Yes	No	N/A	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 031	M	Y-A	N/A	No	No	Yes	N/A	No	No	Yes	No	No	No	No	Yes	No	No	No	N/A	Yes	Yes	Yes	N/A	N/A	N/A	N/A	N/A	No	Yes	Yes	N/A	N/A	N/A	N/A
Morro 1	Tumba 28 C7	M	M-A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 28 C22	M	M-A	Yes	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	N/A	No	N/A	No	Yes	No	N/A	Yes	No	N/A	N/A	Yes	N/A	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Morro 1	Tumba 27 C4	M	Y-A	No	Yes	N/A	Yes	No	No	N/A	N/A	Yes	N/A	Yes	No	Yes	Yes	N/A	Yes	No	Yes	Yes	Yes	Yes	N/A	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes
Morro 1	Tumba 23 C4	F	M-A	No	N/A	N/A	N/A	Yes	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	No	Yes	Yes	N/A	Yes	No	N/A	N/A	N/A	Yes	N/A	N/A
Morro 1	Tumba 28 C9	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	N/A	No	Yes	Yes	N/A	N/A	N/A	N/A
Morro1/5	Tumba XVII (5)	F	M-A	Yes	N/A	N/A	N/A	Yes	Yes	Yes	N/A	No	N/A	N/A	No	Yes	Yes	N/A	Yes	Yes	N/A	Yes	Yes	No	Yes	N/A	N/A	Yes	No	Yes	Yes	N/A	No	N/A	N/A
Morro1/5	Tumba 7	M	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	No	N/A	No	No	No	No	N/A	No	N/A	N/A	No	N/A	Yes	N/A	No	No	N/A	No	N/A	No	N/A	N/A
Morro1/5	Tumba I	M	Y-A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	Yes	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro1/6	Tumba 2	F	M-A	Yes	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	No	No	Yes	No	No	No	Yes	No	No	No	N/A	N/A
Morro1/6	Tumba 6 C1	M	M-A	Yes	N/A	N/A	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	N/A	Yes	Yes	N/A	Yes	N/A	N/A	N/A	N/A	Yes	Yes	No	N/A	N/A	Yes	Yes	Yes	N/A	N/A
Morro1/6	Tumba 7	M	M-A	No	Yes	Yes	Yes	N/A	Yes	Yes	Yes	No	N/A	Yes	N/A	N/A	N/A	No	Yes	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	No	Yes	N/A	Yes	N/A	Yes	N/A	N/A
Morro1/6	Tumba 13	F	Y-A	No	N/A	N/A	No	No	No	No	No	No	N/A	No	N/A	No	N/A	N/A	No	N/A	Yes	N/A	N/A	No	No	No	N/A	N/A	No	No	No	No	No	N/A	N/A
Morro1/6	Tumba 3	F	Y-A	No	N/A	N/A	No	No	No	N/A	No	No	No	Yes	N/A	N/A	Yes	N/A	No	N/A	No	N/A	Yes	Yes	N/A	Yes	N/A	Yes	N/A	N/A	Yes	N/A	No	N/A	N/A
Morro1/6	Tumba 14	M	Y-A	No	N/A	N/A	No	No	N/A	N/A	No	No	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	No	No	No	Yes	N/A	N/A	No	No	No	N/A	N/A
Morro1/6	Tumba 22	M	Y-A	N/A	N/A	N/A	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	N/A	No	N/A	N/A	Yes	N/A	Yes	N/A	N/A
Morro1/6	Tumba 32	F	M-A	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	N/A	Yes	Yes	No	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A

Appendix 1: Enthesophytes of coastal fishers

Site	Skeleton ID	Sex	Age	Costal tuberosity L	Lesser tubercle L	Greater tubercle L	Deltoid tuberosity L	Costal tuberosity R	Lesser tubercle R	Greater tubercle R	Deltoid tuberosity R	Medial epicondyle L	Lateral epicondyle L	Radial tuberosity L	Olecranon L	Ulnar tuberosity L	Medial epicondyle R	Lateral epicondyle R	Radial tuberosity R	Olecranon R	Ulnar tuberosity R	Ischial tuberosity L	Ischial tuberosity R	Lesser trochanter L	Greater trochanter L	Linea aspera L	Tibial tuberosity L	Soleal line L	Lesser trochanter R	Greater trochanter R	Linea aspera R	Tibial tuberosity R	Soleal line R	Calcaneal tuberosity L	Calcaneal tuberosity R
Morro1/6	Tumba 17	M	O-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	Yes	N/A	N/A	Yes	Yes	Yes	N/A	Yes	N/A	No	N/A	N/A	N/A	N/A	No	N/A	N/A
Morro1/6	Tumba 4	M	Y-A	Yes	N/A	N/A	Yes	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	Yes	N/A	Yes	No	Yes	Yes	Yes	No	N/A	Yes	No	No	N/A	Yes	Yes	No	No	N/A	N/A
Morro1/6	Tumba 21	M	M-A	Yes	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	No	No	Yes	N/A	N/A	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	N/A	No	N/A	N/A	Yes	Yes	No	N/A	N/A
Morro1/6	Tumba 9	M	O-A	No	N/A	No	No	No	N/A	N/A	No	N/A	N/A	Yes	N/A	No	N/A	N/A	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A	No	N/A	Yes	N/A	No	N/A	N/A
Morro1/6	Tumba 5	F	Y-A	No	No	No	No	N/A	No	No	No	No	No	No	N/A	No	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	N/A	No	No	Yes	Yes	N/A	No	N/A	N/A
Morro1/6	Tumba 41	M	O-A	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	No	Yes	Yes	N/A	Yes	Yes	N/A	No	N/A	N/A	Yes	N/A	No	N/A	N/A
Morro1/6	Tumba 23	M	Y-A	No	N/A	N/A	Yes	N/A	N/A	N/A	Yes	N/A	N/A	Yes	N/A	No	N/A	N/A	Yes	N/A	Yes	No	No	No	No	Yes	No	No	N/A	No	Yes	No	No	N/A	N/A
Morro1/6	Tumba 46	F	Y-A	Yes	N/A	N/A	Yes	No	Yes	No	Yes	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	Yes	No	N/A	N/A	N/A	Yes	N/A	No	Yes	No	Yes	No	Yes	N/A	N/A
Morro1/6	Tumba 58	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	No	No	Yes	N/A	N/A	No	No	N/A	Yes	N/A	No	N/A	N/A
Morro1/6	Tumba 55	F	Y-A	No	N/A	N/A	N/A	Yes	No	No	No	N/A	N/A	N/A	N/A	N/A	No	No	No	N/A	Yes	Yes	Yes	No	Yes	Yes	N/A	No	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Morro1/6	Tumba 53	F	Y-A	Yes	N/A	N/A	N/A	Yes	No	No	Yes	N/A	N/A	N/A	N/A	No	No	No	No	No	Yes	Yes	No	No	No	Yes	N/A	No	Yes	No	Yes	N/A	No	N/A	N/A
Morro1/6	Tumba 60	F	Y-A	Yes	N/A	No	No	Yes	No	No	No	No	No	No	No	Yes	No	No	N/A	No	Yes	N/A	N/A	No	No	No	N/A	No	No	No	No	N/A	No	N/A	N/A
Morro1/6	U7	M	Y-A	No	No	N/A	N/A	Yes	No	No	Yes	Yes	Yes	N/A	N/A	N/A	Yes	Yes	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	No	N/A	N/A	Yes	Yes	Yes	N/A	N/A
Morro1/6	U1	F	O-A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	N/A	N/A	N/A	Yes	N/A	N/A
Morro1/6	Tumba 50	M	Y-A	Yes	Yes	N/A	N/A	Yes	Yes	N/A	Yes	Yes	N/A	No	No	No	N/A	N/A	No	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	Yes	No	No	N/A	N/A
Morro1/6	Tumba 10 A	F	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	No	N/A	No	N/A	N/A	No	N/A	No	Yes	Yes	No	N/A	Yes	N/A	No	No	N/A	Yes	N/A	No	N/A	N/A
Morro1/6	Tumba 18	M	M-A	No	N/A	N/A	No	No	No	N/A	Yes	No	N/A	N/A	N/A	No	No	N/A	Yes	No	Yes	Yes	No	N/A	N/A	Yes	N/A	N/A	Yes	Yes	Yes	N/A	N/A	N/A	N/A
Morro1/6	Tumba 29	M	M-A	No	N/A	N/A	No	No	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	No	N/A	Yes	N/A	No	N/A	N/A	No	N/A	No	N/A	N/A
Morro1/6	Tumba U5	M	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	N/A	N/A	Yes	N/A	No	N/A	N/A	Yes	N/A	N/A	N/A	N/A
Morro1/6	Tumba U3	F	Y-A	N/A	N/A	N/A	No	N/A	N/A	N/A	No	Yes	N/A	N/A	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	No	No	N/A	No	N/A	No	N/A	N/A
Morro1/6	Tumba 52	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	No	N/A	N/A	N/A	No	No	N/A	Yes	N/A	No	N/A	N/A
Morro1/6	Tumba 34	F	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	No	No	Yes	Yes	Yes	No	Yes	Yes	N/A	N/A	Yes	Yes	Yes	N/A	N/A	N/A	N/A
Morro1/6	Tumba 40	F	O-A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	N/A	No	N/A	N/A	N/A	Yes	No	N/A	Yes	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Quiani 7	Tumba 17	F	M-A	No	No	No	Yes	No	No	N/A	Yes	N/A	N/A	No	No	N/A	No	N/A	No	N/A	No	N/A	No	N/A	N/A	N/A	N/A	N/A	No	Yes	Yes	No	Yes	N/A	N/A
Quiani 7	Tumba 22	M	O-A	Yes	N/A	N/A	N/A	Yes	N/A	N/A	Yes	N/A	N/A	Yes	N/A	N/A	Yes	Yes	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes	N/A	No	Yes	Yes	Yes	Yes	Yes	N/A	Yes

Appendix 1: Enthesophytes of coastal fishers

Site	Skeleton ID	Sex	Age	Costal tuberosity L	Lesser tubercle L	Greater tubercle L	Deltoid tuberosity L	Costal tuberosity R	Lesser tubercle R	Greater tubercle R	Deltoid tuberosity R	Medial epicondyle L	Lateral epicondyle L	Radial tuberosity L	Olecranon L	Ulnar tuberosity L	Medial epicondyle R	Lateral epicondyle R	Radial tuberosity R	Olecranon R	Ulnar tuberosity R	Ischial tuberosity L	Ischial tuberosity R	Lesser trochanter L	Greater trochanter L	Linea aspera L	Tibial tuberosity L	Soleal line L	Lesser trochanter R	Greater trochanter R	Linea aspera R	Tibial tuberosity R	Soleal line R	Calcaneal tuberosity L	Calcaneal tuberosity R
Azapa 71	Tumba B 1	F	M-A	No	No	N/A	Yes	Yes	No	No	N/A	No	N/A	No	N/A	N/A	No	N/A	No	No	No	N/A	N/A	No	N/A	Yes	Yes	No	No	N/A	Yes	Yes	No	N/A	N/A
Azapa 71	Tumba CC	M	Y-A	Yes	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	No	N/A	Yes	N/A	Yes	N/A	N/A	Yes	Yes	Yes	N/A	N/A
Azapa 71	Tumba 103	F	O-A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	Yes	Yes	N/A	N/A	Yes	Yes	N/A	Yes	N/A	Yes	Yes	N/A	No	N/A	N/A
Azapa 71	Tumba 102	F	M-A	Yes	No	No	Yes	Yes	No	No	Yes	N/A	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	N/A	Yes	N/A	N/A
Azapa 71	Tumba 84 B	F	Y-A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	No	N/A	N/A	No	Yes	No	N/A	N/A	N/A	N/A	N/A	N/A
Azapa 71	Tumba BB	F	O-A	Yes	Yes	N/A	Yes	Yes	Yes	N/A	Yes	N/A	Yes	No	No	Yes	N/A	Yes	No	No	N/A	N/A	N/A	N/A	Yes	Yes	No	Yes	N/A	Yes	Yes	N/A	Yes	N/A	N/A
Azapa 71	Tumba E1	F	Y-A	No	Yes	No	No	Yes	No	No	Yes	No	No	No	No	Yes	No	No	Yes	No	Yes	Yes	Yes	N/A	Yes	Yes	No	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes
Azapa 71	Tumba 606 A	M	Y-A	Yes	No	No	Yes	N/A	No	No	No	No	No	No	No	No	No	N/A	No	No	Yes	N/A	No	No	Yes	No	N/A	N/A	No	N/A	No	No	No	N/A	N/A
Azapa 71	Tumba 605	F	O-A	Yes	No	No	Yes	Yes	No	N/A	Yes	No	No	Yes	No	Yes	Yes	No	No	N/A	No	Yes	Yes	N/A	N/A	Yes	No	No	No	Yes	Yes	N/A	Yes	Yes	Yes
Azapa 71	Tumba 601	M	O-A	No	Yes	N/A	Yes	N/A	Yes	N/A	Yes	Yes	Yes	N/A	Yes	N/A	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	N/A	N/A	N/A	N/A
Azapa 71	Tumba 287 B	F	M-A	Yes	No	No	Yes	Yes	Yes	No	No	N/A	N/A	No	N/A	N/A	No	Yes	No	No	N/A	N/A	Yes	N/A	N/A	N/A	N/A	Yes	No	Yes	Yes	N/A	No	N/A	Yes
Azapa 71	Tumba 282	M	M-A	Yes	No	No	Yes	No	No	No	N/A	Yes	No	N/A	No	Yes	No	No	N/A	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	Yes	Yes	No	N/A	N/A
Azapa 71	Tumba 245	F	M-A	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	No	Yes	N/A	No	Yes	No	N/A	No	N/A	Yes	Yes	Yes	Yes	Yes	No	Yes	No	N/A	Yes	No	Yes	N/A	Yes
Azapa 71	Tumba 264	F	Y-A	No	No	No	N/A	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	N/A
Azapa 71	Tumba 194	M	M-A	Yes	Yes	No	N/A	N/A	Yes	N/A	Yes	No	No	N/A	N/A	N/A	No	N/A	N/A	No	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	No	Yes	No	Yes
Azapa 71	Tumba 108 E4	M	M-A	N/A	No	No	N/A	No	No	No	N/A	No	No	No	N/A	N/A	No	No	No	N/A	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	N/A	N/A	Yes	Yes
Azapa 71	Tumba 206	F	Y-A	N/A	No	No	Yes	Yes	No	No	No	No	No	No	N/A	Yes	No	No	No	No	Yes	No	No	No	No	Yes	No	Yes	No	N/A	No	N/A	Yes	N/A	N/A
Azapa 71	Tumba 617	M	M-A	Yes	Yes	N/A	Yes	N/A	Yes	N/A	No	N/A	N/A	No	N/A	N/A	Yes	No	No	Yes	N/A	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Azapa 71	Tumba 265	M	M-A	Yes	No	N/A	N/A	N/A	Yes	No	N/A	Yes	Yes	Yes	No	No	Yes	No	Yes	N/A	Yes	N/A	N/A	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	N/A	N/A
Azapa 71	Tumba 205	M	M-A	No	No	No	Yes	N/A	No	No	Yes	N/A	N/A	Yes	N/A	No	Yes	N/A	Yes	N/A	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 71	Tumba 256 A	F	O-A	Yes	N/A	No	Yes	Yes	N/A	No	Yes	N/A	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	N/A	Yes	Yes	Yes
Azapa 71	Tumba 215	F	M-A	Yes	No	No	Yes	Yes	Yes	N/A	Yes	No	No	No	N/A	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	N/A	No	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 71	Tumba A1	F	M-A	Yes	N/A	No	No	N/A	N/A	No	Yes	N/A	No	No	No	Yes	No	No	No	N/A	Yes	No	Yes	No	N/A	Yes	Yes	No	No	N/A	Yes	Yes	Yes	N/A	N/A
Azapa 71	Tumba 290	F	Y-A	N/A	No	No	Yes	Yes	N/A	N/A	N/A	No	No	No	Yes	No	N/A	N/A	N/A	N/A	N/A	No	No	No	Yes	Yes	Yes	Yes	N/A	No	Yes	No	Yes	Yes	Yes
Azapa 71	Tumba 607	F	M-A	N/A	N/A	N/A	Yes	Yes	No	No	No	No	No	N/A	N/A	N/A	No	No	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	No	N/A	Yes	Yes	Yes	N/A	N/A

Appendix 1: Enthesophytes of coastal fishers

Site	Skeleton ID	Sex	Age	Costal tuberosity L	Lesser tubercle Hum L	Greater tubercle L	Deltoid tuberosity L	Costal tuberosity R	Lesser tubercle Hum R	Greater tubercle R	Deltoid tuberosity R	Medial epicondyle L	Lateral epicondyle L	Radial tuberosity L	Olecranon L	Ulnar tuberosity L	Medial epicondyle R	Lateral epicondyle R	Radial tuberosity R	Olecranon R	Ulnar tuberosity R	Ischial tuberosity L	Ischial tuberosity R	Lesser trochanter L	Greater trochanter L	Linea aspera L	Tibial tuberosity L	Soleal line L	Lesser trochanter R	Greater trochanter R	Linea aspera R	Tibial tuberosity R	Soleal line R	Calcaneal tuberosity L	Calcaneal tuberosity R
Azapa 71	Tumba 615	F	Y-A	N/A	N/A	N/A	No	N/A	No	N/A	No	No	No	No	No	No	No	No	No	No	No	N/A	N/A	N/A	N/A	No	Yes	Yes	N/A	N/A	Yes	No	Yes	N/A	N/A
Azapa 71	Tumba 616	F	M-A	Yes	N/A	N/A	Yes	Yes	N/A	N/A	No	Yes	Yes	No	No	N/A	N/A	Yes	No	N/A	No	N/A	N/A	N/A	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	N/A
Azapa 71	Tumba DD	F	M-A	Yes	Yes	N/A	Yes	No	N/A	N/A	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	N/A	N/A	N/A	No	N/A	Yes	N/A	Yes	No	Yes	Yes	No	Yes	N/A	N/A
Azapa 71	Tumba 101 A	F	Y-A	No	No	N/A	N/A	Yes	N/A	N/A	No	N/A	No	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	Yes	No	N/A	Yes	N/A	Yes	N/A	N/A
Azapa 71	Tumba 104	F	Y-A	Yes	No	N/A	Yes	N/A	No	N/A	No	No	Yes	No	No	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	Yes	No	No	Yes	No	Yes	No	No
Azapa 71	Tumba 400	M	Y-A	Yes	No	No	Yes	N/A	No	N/A	Yes	No	N/A	Yes	No	Yes	Yes	No	Yes	No	No	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Azapa 140	Tumba 8	F	M-A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	N/A	N/A	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 4	F	Y-A	No	No	No	No	No	N/A	Yes	Yes	No	No	No	No	N/A	No	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Azapa 140	Tumba 5	F	M-A	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	No	Yes	No	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Azapa 140	Tumba 18	F	Y-A	No	No	No	Yes	N/A	No	No	Yes	No	N/A	Yes	No	Yes	Yes	No	Yes	No	Yes	N/A	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	N/A	N/A
Azapa 140	Tumba 27	F	O-A	Yes	No	No	Yes	Yes	No	No	Yes	No	No	Yes	No	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes
Azapa 140	Tumba 52	M	M-A	Yes	No	No	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	N/A	Yes	N/A	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 32	F	O-A	Yes	No	N/A	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 35	M	Y-A	No	No	No	No	Yes	N/A	N/A	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	N/A	No	No	No	Yes	N/A	No	No	No
Azapa 140	Tumba 38	M	Y-A	No	No	N/A	No	No	No	No	No	No	N/A	Yes	N/A	Yes	N/A	No	N/A	No	Yes	N/A	Yes	No	Yes	Yes	N/A	No	N/A	Yes	Yes	N/A	No	N/A	N/A
Azapa 140	Tumba 75	M	M-A	Yes	No	N/A	Yes	N/A	No	No	Yes	No	No	N/A	N/A	N/A	No	No	No	No	Yes	N/A	Yes	No	N/A	Yes	No	Yes	No	N/A	Yes	No	Yes	N/A	N/A
Azapa 140	Tumba 45B	F	Y-A	Yes	No	No	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 51	F	Y-A	No	No	No	Yes	N/A	No	No	Yes	No	No	Yes	No	Yes	N/A	No	Yes	N/A	Yes	No	No	No	No	No	N/A	No	No	No	No	N/A	No	N/A	N/A
Azapa 140	Tumba 49	F	Y-A	No	No	No	Yes	Yes	N/A	N/A	N/A	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	N/A	N/A	Yes	Yes	N/A	No	Yes	Yes	Yes	N/A	N/A
Azapa 140	Tumba 55	M	M-A	N/A	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	N/A	Yes	Yes	Yes	No	N/A	N/A	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Azapa 140	Tumba 81	F	O-A	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	N/A	Yes	No	No	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Azapa 140	Tumba 58	F	O-A	Yes	No	No	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes	No	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Azapa 140	Tumba 7	M	O-A	Yes	Yes	Yes	Yes	Yes	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	N/A	N/A	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 16	M	M-A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Azapa 140	Tumba 23	M	M-A	N/A	Yes	Yes	N/A	N/A	Yes	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A

Appendix 1: Enthesophytes of inland agriculturalists

Site	Skeleton ID	Sex	Age	Costal tuberosity L	Lesser tubercle L	Greater tubercle L	Deltoid tuberosity L	Costal tuberosity R	Lesser tubercle R	Greater tubercle R	Deltoid tuberosity R	Medial epicondyle L	Lateral epicondyle L	Radial tuberosity L	Olecranon L	Ulnar tuberosity L	Medial epicondyle R	Lateral epicondyle R	Radial tuberosity R	Olecranon R	Ulnar tuberosity R	Ischial tuberosity L	Ischial tuberosity R	Lesser trochanter L	Greater trochanter L	Linea aspera L	Tibial tuberosity L	Soleal line L	Lesser trochanter R	Greater trochanter R	Linea aspera R	Tibial tuberosity R	Soleal line R	Calcaneal tuberosity L	Calcaneal tuberosity R
Azapa 140	Tumba 36	M	Y-A	Yes	Yes	N/A	Yes	Yes	Yes	N/A	Yes	Yes	N/A	No	N/A	Yes	Yes	N/A	Yes	N/A	Yes	N/A	N/A	N/A	N/A	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	N/A	No
Azapa 140	Tumba 93	F	O-A	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Azapa 140	Tumba 39	F	Y-A	No	N/A	N/A	Yes	No	Yes	No	Yes	No	No	N/A	N/A	N/A	No	No	Yes	N/A	Yes	N/A	N/A	N/A	N/A	Yes	No	Yes	No	Yes	Yes	No	Yes	N/A	N/A
Azapa 140	Tumba 10	F	Y-A	Yes	No	No	Yes	Yes	No	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	N/A	N/A	No	N/A	Yes	No	No	No	N/A
Azapa 140	Tumba 19	F	O-A	N/A	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 77	F	O-A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	N/A	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	N/A	Yes
Azapa 140	Tumba 73	F	M-A	N/A	N/A	N/A	Yes	Yes	N/A	N/A	N/A	Yes	Yes	N/A	N/A	Yes	N/A	N/A	Yes	N/A	Yes	Yes	Yes	No	Yes	Yes	No	Yes	N/A	N/A	N/A	No	Yes	Yes	N/A
Azapa 140	Tumba 64 A	M	M-A	No	N/A	N/A	Yes	No	N/A	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	N/A	N/A
Azapa 140	Tumba 97	M	M-A	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	N/A	No	N/A	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
Azapa 140	Tumba 99	M	Y-A	No	No	No	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	No	No	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	N/A	N/A
Azapa 140	Tumba 63	F	M-A	Yes	Yes	N/A	Yeses	No	N/A	N/A	Yes	N/A	N/A	N/A	N/A	No	Yes	Yes	N/A	N/A	No	N/A	N/A	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	N/A	N/A
Azapa 140	Tumba 104	M	Y-A	Yes	N/A	N/A	N/A	Yes	Yes	No	Yes	Yes	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	N/A	N/A
Azapa 140	Tumba 105	M	M-A	Yes	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	N/A	N/A	N/A	N/A	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	N/A
Azapa 140	Tumba 100	F	M-A	Yes	N/A	N/A	Yes	N/A	Yes	N/A	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	N/A	No
Azapa 140	Tumba 113	M	Y-A	No	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No	No	No	Yes	N/A	N/A	No	No	Yes	No	No
Azapa 140	Tumba 128	M	M-A	No	Yes	No	Yes	No	Yes	No	Yes	No	N/A	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 108A	M	M-A	Yes	N/A	N/A	Yes	Yes	Yes	N/A	Yes	N/A	N/A	Yes	No	N/A	Yes	N/A	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 116	F	Y-A	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	Yes
Azapa 140	Tumba 122	M	M-A	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	N/A	Yes
Azapa 140	Desc 1	M	O-A	N/A	Yes	Yes	Yes	Yes	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	N/A	N/A	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A	N/A	Yes
Azapa 140	XPB 6	M	M-A	No	N/A	N/A	N/A	No	N/A	N/A	Yes	N/A	N/A	Yes	N/A	Yes	Yes	Yes	N/A	N/A	N/A	Yes	Yes	N/A	Yes	Yes	N/A	Yes	N/A	N/A	Yes	N/A	Yes	N/A	N/A
Azapa 140	Tumba 117	F	M-A	Yes	N/A	N/A	N/A	Yes	No	No	No	N/A	N/A	N/A	N/A	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes	Yes	Yes	N/A	Yes	Yes	Yes
Azapa 140	Tumba125	F	M-A	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Azapa 140	Tumba 124	F	M-A	Yes	No	N/A	N/A	Yes	No	Yes	Yes	Yes	N/A	N/A	No	Yes	No	No	N/A	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	N/A	Yes
Azapa 140	Tumba 112A	F	O-A	Yes	N/A	N/A	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	N/A	N/A	Yes	No	Yes	Yes	No	Yes	No	Yes	N/A	Yes	Yes	Yes	Yes	Yes	N/A

Appendix 1: Enthesophytes of inland agriculturalists

Site	Skeleton ID	Sex	Age	Costal tuberosity L	Lesser tubercle L	Greater tubercle L	Deltoid tuberosity L	Costal tuberosity R	Lesser tubercle R	Greater tubercle R	Deltoid tuberosity R	Medial epicondyle L	Lateral epicondyle L	Radial tuberosity L	Olecranon L	Ulnar tuberosity L	Medial epicondyle R	Lateral epicondyle R	Radial tuberosity R	Olecranon R	Ulnar tuberosity R	Ischial tuberosity L	Ischial tuberosity R	Lesser trochanter L	Greater trochanter L	Linea aspera L	Tibial tuberosity L	Soleal line L	Lesser trochanter R	Greater trochanter R	Linea aspera R	Tibial tuberosity R	Soleal line R	Calcaneal tuberosity L	Calcaneal tuberosity R
Azapa 140	Tumba 110	F	M-A	Yes	No	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes
Azapa 140	Tumba 126	F	O-A	Yes	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba XPB 2A	M	Y-A	No	N/A	N/A	Yes	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	No	N/A	No	N/A	N/A	No	No	No	N/A	N/A	No	No	Yes	N/A	N/A
Azapa 140	Tumba XPB	F	Y-A	No	N/A	N/A	No	No	No	No	N/A	No	No	Yes	No	Yes	N/A	No	N/A	Yes	No	No	No	No	Yes	Yes	No	No	No	Yes	Yes	No	No	No	No
Azapa 140	Tumba 41	F	M-A	N/A	N/A	N/A	No	Yes	N/A	N/A	No	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	Yes	No	No	Yes	Yes	N/A	Yes	N/A	N/A	Yes	N/A	Yes	Yes	N/A
Azapa 140	Tumba 50	F	M-A	Yes	Yes	No	Yes	Yes	No	N/A	Yes	No	No	Yes	No	Yes	No	No	No	No	Yes	N/A	N/A	Yes	Yes	Yes	No	Yes	Yes	N/A	Yes	No	Yes	N/A	N/A
Azapa 140	Tumba 56	F	O-A	Yes	N/A	N/A	Yes	No	No	N/A	No	N/A	Yes	N/A	N/A	Yes	N/A	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	No	Yes	Yes	No	Yes	N/A	Yes
Azapa 140	Tumba 290	F	Y-A	N/A	No	No	Yes	Yes	N/A	N/A	N/A	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	No	No	No	No	Yes	No	Yes	N/A	Yes	Yes	No	Yes	Yes	Yes
Azapa 140	Tumba 47	F	M-A	N/A	No	N/A	Yes	N/A	N/A	N/A	Yes	No	Yes	Yes	No	N/A	No	N/A	Yes	No	Yes	Yes	N/A	N/A	Yes	Yes	N/A	Yes	N/A	N/A	Yes	N/A	Yes	N/A	N/A
Azapa 140	Tumba 42A	F	M-A	N/A	N/A	Yes	Yes	N/A	Yes	N/A	N/A	N/A	Yes	No	No	N/A	Yes	Yes	No	N/A	Yes	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A	N/A
Azapa 140	Tumba 63	F	M-A	N/A	No	N/A	Yes	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	N/A	N/A	No	No	No	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	N/A	N/A
Azapa 140	Tumba 111	F	Y-A	Yes	Yes	No	Yes	Yes	No	N/A	Yes	No	No	Yes	N/A	Yes	Yes	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Azapa 140	Tumba 79	F	Y-A	Yes	No	No	No	Yes	No	No	No	No	No	No	No	Yes	No	No	No	No	No	N/A	No	No	N/A	No	No	No	No	N/A	No	No	No	N/A	N/A
Azapa 140	Tumba 78	F	Y-A	No	No	N/A	No	No	No	No	No	No	N/A	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	No	No	Yes	N/A	Yes	Yes	Yes	No	N/A	Yes	N/A	Yes	N/A	Yes
Azapa 141	Tumba 22	M	Y-A	Yes	No	No	N/A	N/A	No	No	Yes	No	N/A	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Azapa 141	Tumba 33	M	M-A	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Azapa 141	Tumba 36	M	Y-A	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	N/A	No	N/A	Yes	N/A	N/A
Azapa 141	Tumba 26	M	Y-A	Yes	No	No	No	Yes	N/A	N/A	No	No	N/A	N/A	No	N/A	N/A	No	No	N/A	No	N/A	N/A	N/A	N/A	No	No	No	No	N/A	Yes	N/A	No	N/A	N/A
Azapa 141	Tumba 43	F	M-A	No	No	N/A	No	No	N/A	N/A	No	N/A	No	N/A	N/A	N/A	No	No	No	N/A	No	N/A	Yes	N/A	N/A	Yes	No	No	N/A	N/A	Yes	N/A	N/A	N/A	N/A
Azapa 141	Desc 02	F	M-A	No	No	No	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	N/A	N/A	Yes	N/A	Yes	N/A	Yes
Azapa 141	Tumba 46	M	M-A	No	No	No	No	Yes	N/A	N/A	Yes	No	No	No	No	Yes	N/A	No	No	N/A	Yes	Yes	N/A	No	N/A	Yes	N/A	N/A	No	N/A	Yes	N/A	Yes	N/A	N/A
Azapa 141	Tumba 52	M	M-A	N/A	N/A	No	No	N/A	No	N/A	No	No	No	N/A	No	Yes	No	No	No	No	Yes	No	Yes	N/A	N/A	Yes	Yes	No	No	N/A	Yes	Yes	No	N/A	N/A
Azapa 141	Tumba 49	F	Y-A	Yes	No	No	Yes	Yes	No	No	Yes	N/A	No	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	No	N/A	Yes	No	Yes	No	N/A	Yes	No	Yes	Yes	No
Azapa 141	Tumba 53	M	Y-A	N/A	No	No	Yes	N/A	No	No	Yes	No	No	No	No	N/A	No	No	No	No	N/A	Yes	Yes	No	No	N/A	No	N/A	No	No	N/A	No	N/A	Yes	Yes
Azapa 141	Tumba 37	F	M-A	Yes	No	No	Yes	N/A	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	Yes	No	N/A	Yes	Yes	Yes	N/A	Yes

Appendix 1: Enthesophytes of inland agriculturalists

Site	Skeleton ID	Sex	Age	L Acromio-clavicular	L Gleno-humeral	R Acromio-clavicular	R Gleno-humeral	L Humero-radial	L Humero-ulnar	L Radio-ulnar	R Humero-radial	R Humero-ulnar	R Radio-ulnar	L Coxo-femoral	R Coxo-femoral	L Femoro-tibial	L Femoro-patellar	R Femoro-tibial	R Femoro-patellar	L Tibio-astragalina	R Tibio-astragalina
Morro 1	Tumba 3	F	O-A	N/A	N/A	N/A	N/A	YES	N/A	NO	YES	NO	NO	NO	NO	YES	N/A	YES	N/A	NO	NO
Morro 1	Tumba 9	F	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	N/A	YES	NO	N/A	NO	NO	NO	N/A	N/A
Morro 1	Tumba 4	M	Y-A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	NO	NO	NO	N/A	NO
Morro 1	Tumba 10A	M	Y-A	NO	N/A	NO	NO	NO	NO	NO	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO
Morro 1	Tumba 10B	F	M-A	YES	YES	N/A	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	NO	NO
Morro 1	Tumba 12	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	N/A	N/A
Morro 1	Tumba 12B	F	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO
Morro 1	Tumba 22C-5	F	Y-A	YES	N/A	N/A	N/A	N/A	NO	N/A	YES	N/A	YES	NO	NO	NO	NO	NO	NO	NO	NO
Morro 1	Tumba 19 C-1	M	Y-A	NO	NO	NO	NO	NO	N/A	N/A	NO	NO	NO	NO	NO	N/A	NO	NO	NO	NO	N/A
Morro 1	Tumba 28	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	NO	N/A	NO	N/A	NO	NO
Morro 1	Tumba 28 C-11	M	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	YES	N/A	N/A	N/A	NO	N/A	N/A
Morro 1	Tumba 28 C-15	F	M-A	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
Morro 1	Tumba 23 C-3	M	Y-A	YES	N/A	YES	NO	N/A	NO	N/A	N/A	N/A	N/A	NO	NO	NO	N/A	NO	N/A	NO	NO
Morro 1	Tumba 15	F	Y-A	NO	NO	NO	NO	N/A	YES	YES	NO	NO	NO	NO	NO	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 28 C-5	F	M-A	N/A	N/A	YES	YES	N/A	N/A	N/A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Morro 1	Tumba 28 C-28	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO
Morro 1	Tumba 27 C-11	M	M-A	YES	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 27 C-10	M	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	N/A	NO	NO
Morro 1	Tumba 27 C-12	M	M-A	N/A	YES	N/A	YES	N/A	NO	N/A	YES	YES	YES	YES	YES	YES	NO	YES	YES	N/A	N/A
Morro 1	Tumba 27 C-8	F	O-A	YES	YES	N/A	N/A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
Morro 1	Tumba 27 C-13	F	M-A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	N/A	YES	NO	N/A	NO
Morro 1	Tumba 16 A	M	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	YES	YES	YES	YES	YES	YES	NO	NO
Morro 1	Tumba 6	F	M-A	N/A	NO	N/A	N/A	YES	YES	YES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 18 C-3	M	M-A	N/A	N/A	N/A	N/A	N/A	YES	N/A	YES	YES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 16 B	M	M-A	N/A	N/A	N/A	NO	YES	YES	YES	YES	YES	YES	YES	YES	N/A	N/A	N/A	N/A	N/A	N/A

Appendix 2: Osteoarthritis of coastal fishers

Site	Skeleton ID	Sex	Age	L Acromio-clavicular	L Gleno-humeral	R Acromio-clavicular	R Gleno-humeral	L Humero-radial	L Humero-ulnar	L Radio-ulnar	R Humero-radial	R Humero-ulnar	R Radio-ulnar	L Coxo-femoral	R Coxo-femoral	L Femoro-tibial	L Femoro-patellar	R Femoro-tibial	R Femoro-patellar	L Tibio-astragalina	R Tibio-astragalina
Morro 1	Tumba 23 C-13	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	N/A	NO	NO
Morro 1	Tumba 23 C-5	F	Y-A	YES	N/A	YES	N/A	NO	NO	NO	YES	YES	N/A	NO	NO	NO	NO	NO	NO	NO	NO
Morro 1	Tumba 8	F	Y-A	YES	N/A	NO	NO	NO	NO	NO	NO	NO	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 27 C-5	M	Y-A	N/A	NO	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Morro 1	Tumba 28 C-10	M	Y-A	YES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	YES	YES	YES	N/A	YES	YES	N/A	N/A
Morro 1	Tumba 23 C-12	F	Y-A	NO	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	N/A	NO	N/A	NO	NO
Morro 1	Tumba 27 C-18	M	M-A	YES	NO	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO
Morro 1	Tumba 25 C-3	M	Y-A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	N/A	N/A
Morro 1	Tumba 031	M	Y-A	N/A	N/A	N/A	N/A	YES	YES	YES	YES	YES	YES	YES	YES	N/A	N/A	N/A	NO	N/A	N/A
Morro 1	Tumba 28 C-7	M	M-A	N/A	N/A	YES	N/A	YES	YES	NO	YES	YES	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Morro 1	Tumba 28 C-22	M	M-A	YES	N/A	N/A	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	N/A	NO
Morro 1	Tumba 27 C-4	M	Y-A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
Morro 1	Tumba 23 C-4	F	M-A	N/A	YES	YES	NO	YES	YES	YES	YES	YES	NO	YES	YES	YES	NO	YES	NO	NO	NO
Morro 1	Tumba 28 C-9	F	Y-A	N/A	N/A	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A
Morro1/5	Tumba XVII (5)	F	M-A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Morro1/5	Tumba 7	M	M-A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Morro1/5	Tumba I	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	N/A	N/A	N/A	N/A
Morro1/6	Tumba 2	F	M-A	NO	N/A	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO
Morro1/6	Tumba 6 C-1	M	M-A	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO	NO	NO
Morro1/6	Tumba 7	M	M-A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	N/A	NO	N/A	NO	NO
Morro1/6	Tumba 13	F	Y-A	N/A	NO	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Morro1/6	Tumba 3	F	Y-A	N/A	NO	NO	NO	NO	N/A	N/A	NO	NO	NO	NO	N/A	NO	N/A	NO	NO	NO	NO
Morro1/6	Tumba 14	M	Y-A	NO	NO	N/A	NO	N/A	N/A	N/A	NO	NO	NO	YES	N/A	NO	NO	NO	N/A	NO	NO
Morro1/6	Tumba 22	M	Y-A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO	NO	NO
Morro1/6	Tumba 32	F	M-A	YES	NO	YES	N/A	YES	YES	YES	YES	YES	NO	YES	N/A	YES	YES	YES	YES	NO	YES

Appendix 2: Osteoarthritis of coastal fishers

Site	Skeleton ID	Sex	Age	L Acromio-clavicular	L Gleno-humeral	R Acromio-clavicular	R Gleno-humeral	L Humero-radial	L Humero-ulnar	L Radio-ulnar	R Humero-radial	R Humero-ulnar	R Radio-ulnar	L Coxo-femoral	R Coxo-femoral	L Femoro-tibial	L Femoro-patellar	R Femoro-tibial	R Femoro-patellar	L Tibio-astragalina	R Tibio-astragalina
Morro1/6	Tumba 17	M	O-A	N/A	N/A	N/A	NO	N/A	N/A	N/A	YES	YES	YES	NO	N/A	YES	YES	N/A	YES	NO	NO
Morro1/6	Tumba 4	M	Y-A	YES	YES	YES	NO	YES	YES	NO	YES	YES	YES	NO	YES	NO	N/A	NO	NO	NO	NO
Morro1/6	Tumba 21	M	M-A	NO	NO	N/A	NO	YES	NO	NO	NO	YES	NO	YES	YES	NO	NO	NO	NO	NO	NO
Morro1/6	Tumba 9	M	O-A	N/A	NO	N/A	N/A	NO	NO	NO	N/A	N/A	N/A	NO	YES	YES	NO	YES	NO	N/A	NO
Morro1/6	Tumba 5	F	Y-A	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Morro1/6	Tumba 41	M	O-A	NO	YES	YES	NO	YES	YES	YES	YES	NO	NO	YES	N/A	YES	N/A	YES	NO	NO	NO
Morro1/6	Tumba 23	M	Y-A	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	N/A	NO	NO
Morro1/6	Tumba 46	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO
Morro1/6	Tumba 58	F	Y-A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Morro1/6	Tumba 55	F	Y-A	NO	N/A	NO	NO	N/A	N/A	N/A	NO	NO	NO	YES	YES	NO	NO	NO	N/A	NO	NO
Morro1/6	Tumba 53	F	Y-A	N/A	N/A	NO	YES	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Morro1/6	Tumba 60	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Morro1/6	U7	M	Y-A	YES	NO	N/A	NO	N/A	N/A	N/A	YES	YES	N/A	NO	N/A	NO	NO	NO	NO	NO	NO
Morro1/6	U1	F	O-A	NO	NO	NO	NO	YES	YES	NO	N/A	NO	N/A	NO	NO	NO	NO	NO	N/A	NO	NO
Morro1/6	Tumba 50	M	Y-A	NO	NO	NO	NO	YES	YES	NO	YES	YES	NO	N/A	N/A	N/A	N/A	NO	N/A	NO	NO
Morro1/6	Tumba 10-A	F	M-A	N/A	N/A	N/A	N/A	NO	NO	NO	N/A	N/A	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Morro1/6	Tumba 18	M	M-A	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	NO	NO	N/A	N/A	N/A	N/A	N/A	N/A
Morro1/6	Tumba 29	M	M-A	YES	NO	YES	NO	YES	NO	YES	YES	NO	YES	NO	N/A	NO	NO	NO	NO	NO	NO
Morro1/6	Tumba U5	M	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	YES	YES	YES	NO	YES	NO	N/A	N/A
Morro1/6	Tumba U3	F	Y-A	NO	NO	N/A	NO	NO	NO	NO	N/A	N/A	N/A	NO	NO	NO	N/A	NO	NO	NO	NO
Morro1/6	Tumba 52	F	Y-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	NO	N/A	NO	NO	NO	NO
Morro1/6	Tumba 34	F	M-A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	YES	YES	NO	YES	N/A	YES	NO	N/A
Morro1/6	Tumba 40	F	O-A	N/A	N/A	N/A	NO	N/A	N/A	YES	YES	YES	YES	NO	N/A	NO	N/A	NO	N/A	YES	NO
Quiani 7	Tumba 17	F	M-A	N/A	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	N/A	NO	NO	N/A	N/A
Quiani 7	Tumba 22	M	O-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A

Appendix 2: Osteoarthritis of coastal fishers

Site	Skeleton ID	Sex	Age	L Acromio-clavicular	L Gleno-humeral	R Acromio-clavicular	R Gleno-humeral	L Humero-radial	L Humero-ulnar	L Radio-ulnar	R Humero-radial	R Humero-ulnar	R Radio-ulnar	L Coxo-femoral	R Coxo-femoral	L Femoro-tibial	L Femoro-patellar	R Femoro-tibial	R Femoro-patellar	L Tibio-astragalina	R Tibio-astragalina
Azapa 71	Tumba B-1	F	M-A	YES	NO	YES	NO	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Azapa 71	Tumba CC	M	Y-A	NO	N/A	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NO	NO	YES	N/A	NO	N/A	N/A	N/A
Azapa 71	Tumba 103	F	O-A	N/A	NO	N/A	NO	NO	NO	N/A	NO	NO	NO	YES	YES	YES	N/A	N/A	NO	NO	NO
Azapa 71	Tumba 102	F	M-A	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 71	Tumba 84-B	F	Y-A	NO	NO	N/A	N/A	NO	NO	NO	NO	NO	NO	N/A	NO	YES	YES	NO	NO	NO	NO
Azapa 71	Tumba BB	F	O-A	YES	YES	YES	YES	NO	NO	NO	NO	YES	NO	NO	NO	YES	N/A	NO	N/A	N/A	N/A
Azapa 71	Tumba E1	F	Y-A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO	N/A	N/A	NO
Azapa 71	Tumba 606 A	M	Y-A	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	N/A	NO	NO	NO	NO
Azapa 71	Tumba 605	F	O-A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
Azapa 71	Tumba 601	M	O-A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
Azapa 71	Tumba 287-B	F	M-A	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	N/A	YES	NO	YES	NO	NO	YES	NO
Azapa 71	Tumba 282	M	M-A	YES	NO	NO	NO	NO	NO	YES	YES	YES	YES	NO	NO	NO	N/A	NO	N/A	N/A	N/A
Azapa 71	Tumba 245	F	M-A	NO	NO	NO	NO	YES	YES	NO	NO	N/A	NO	NO	N/A	NO	NO	NO	NO	NO	NO
Azapa 71	Tumba 264	F	Y-A	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 71	Tumba 194	M	M-A	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO	N/A	NO	NO	NO	NO
Azapa 71	Tumba 108 E4	M	M-A	YES	NO	N/A	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO	N/A	YES	N/A	NO	N/A
Azapa 71	Tumba 206	F	Y-A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Azapa 71	Tumba 617	M	M-A	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	N/A	NO	NO
Azapa 71	Tumba 265	M	M-A	YES	NO	N/A	N/A	YES	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 71	Tumba 205	M	M-A	YES	NO	YES	NO	YES	YES	NO	YES	YES	YES	NO	YES	NO	N/A	YES	YES	N/A	NO
Azapa 71	Tumba 256 A	F	O-A	YES	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	NO	NO	NO
Azapa 71	Tumba 215	F	M-A	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	N/A	NO	N/A	NO	NO
Azapa 71	Tumba A1	F	M-A	NO	NO	YES	NO	YES	YES	NO	YES	YES	NO	YES	YES	NO	NO	N/A	NO	NO	NO
Azapa 71	Tumba 290	F	Y-A	N/A	N/A	N/A	N/A	NO	NO	NO	N/A	N/A	N/A	NO	NO	YES	N/A	NO	N/A	NO	NO
Azapa 71	Tumba 607	F	M-A	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	NO	NO

Appendix 2: Osteoarthritis of inland agriculturalists

Site	Skeleton ID	Sex	Age	L Acromio-clavicular	L Gleno-humeral	R Acromio-clavicular	R Gleno-humeral	L Humero-radial	L Humero-ulnar	L Radio-ulnar	R Humero-radial	R Humero-ulnar	R Radio-ulnar	L Coxo-femoral	R Coxo-femoral	L Femoro-tibial	L Femoro-patellar	R Femoro-tibial	R Femoro-patellar	L Tibio-astragalina	R Tibio-astragalina
Azapa 71	Tumba 615	F	Y-A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Azapa 71	Tumba 616	F	M-A	NO	NO	NO	NO	NO	NO	NO	N/A	N/A	NO	YES	NO	YES	N/A	YES	NO	NO	NO
Azapa 71	Tumba DD	F	M-A	NO	NO	YES	NO	YES	YES	NO	YES	YES	YES	YES	NO	YES	N/A	YES	NO	NO	NO
Azapa 71	Tumba 101 A	F	Y-A	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	N/A
Azapa 71	Tumba 104	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 71	Tumba 400	M	Y-A	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Azapa 140	Tumba 8	F	M-A	N/A	NO	YES	YES	NO	YES	N/A	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES
Azapa 140	Tumba 4	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Azapa 140	Tumba 5	F	M-A	NO	NO	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	N/A	YES	N/A	NO	NO
Azapa 140	Tumba 18	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	NO	NO
Azapa 140	Tumba 27	F	O-A	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES	YES	YES	YES	YES	NO	NO	NO
Azapa 140	Tumba 52	M	M-A	NO	NO	NO	NO	YES	YES	NO	YES	YES	NO	NO	YES	YES	N/A	YES	YES	N/A	NO
Azapa 140	Tumba 32	F	O-A	YES	YES	YES	NO	YES	YES	NO	YES	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES
Azapa 140	Tumba 35	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A
Azapa 140	Tumba 38	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Azapa 140	Tumba 75	M	M-A	N/A	NO	N/A	NO	YES	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO
Azapa 140	Tumba 45B	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 140	Tumba 51	F	Y-A	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	NO	NO
Azapa 140	Tumba 49	F	Y-A	NO	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO
Azapa 140	Tumba 55	M	M-A	NO	NO	N/A	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	N/A	NO	N/A	N/A	NO
Azapa 140	Tumba 81	F	O-A	NO	YES	YES	YES	NO	NO	YES	NO	NO	NO	YES	YES	NO	YES	NO	NO	NO	NO
Azapa 140	Tumba 58	F	O-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Azapa 140	Tumba 7	M	O-A	NO	NO	NO	NO	NO	NO	NO	YES	N/A	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 140	Tumba 16	M	M-A	NO	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
Azapa 140	Tumba 23	M	M-A	N/A	NO	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO

Appendix 2: Osteoarthritis of inland agriculturalists

Site	Skeleton ID	Sex	Age	L Acromio-clavicular	L Gleno-humeral	R Acromio-clavicular	R Gleno-humeral	L Humero-radial	L Humero-ulnar	L Radio-ulnar	R Humero-radial	R Humero-ulnar	R Radio-ulnar	L Coxo-femoral	R Coxo-femoral	L Femoro-tibial	L Femoro-patellar	R Femoro-tibial	R Femoro-patellar	L Tibio-astragalina	R Tibio-astragalina
Azapa 140	Tumba 36	M	Y-A	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	N/A	NO
Azapa 140	Tumba 93	F	O-A	N/A	NO	N/A	NO	YES	YES	YES	YES	YES	NO	YES	YES	NO	NO	NO	YES	NO	NO
Azapa 140	Tumba 39	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 140	Tumba 10	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	N/A	NO	NO	NO	NO
Azapa 140	Tumba 19	F	O-A	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	N/A	YES	YES	YES	YES	YES	YES
Azapa 140	Tumba 77	F	O-A	N/A	N/A	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	NO	NO
Azapa 140	Tumba 73	F	M-A	NO	NO	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	N/A	NO	NO
Azapa 140	Tumba 64 A	M	M-A	NO	NO	NO	N/A	N/A	NO	N/A	N/A	N/A	NO	N/A	NO	NO	NO	NO	NO	N/A	NO
Azapa 140	Tumba 97	M	M-A	NO	YES	YES	NO	YES	YES	YES	YES	YES	YES	NO	YES	YES	NO	YES	NO	NO	NO
Azapa 140	Tumba 99	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	NO	NO	NO	N/A	N/A
Azapa 140	Tumba 63	F	M-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	N/A	N/A
Azapa 140	Tumba 104	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Azapa 140	Tumba 105	M	M-A	YES	NO	YES	NO	NO	NO	NO	YES	YES	N/A	YES	YES	NO	NO	YES	N/A	N/A	NO
Azapa 140	Tumba 100	F	M-A	NO	NO	YES	NO	YES	YES	N/A	YES	YES	NO	NO	NO	NO	N/A	NO	N/A	N/A	N/A
Azapa 140	Tumba 113	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO	NO	NO	NO	NO
Azapa 140	Tumba 128	M	M-A	YES	NO	YES	NO	NO	YES	NO	NO	NO	NO	NO	NO	YES	N/A	YES	N/A	NO	NO
Azapa 140	Tumba 108A	M	M-A	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Azapa 140	Tumba 116	F	Y-A	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	N/A	NO	N/A	N/A	NO
Azapa 140	Tumba 122	M	M-A	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	N/A	NO
Azapa 140	Desconocido 1	M	O-A	YES	NO	YES	N/A	YES	YES	YES	N/A	YES	YES	YES	YES	YES	YES	YES	YES	YES	N/A
Azapa 140	XPB-6	M	M-A	NO	NO	NO	NO	YES	NO	NO	YES	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO
Azapa 140	Tumba 117	F	M-A	N/A	N/A	NO	NO	N/A	N/A	N/A	YES	YES	NO	NO	YES	YES	N/A	YES	N/A	NO	NO
Azapa 140	Tumba125	F	M-A	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	YES	YES	NO	YES	YES	NO	NO
Azapa 140	Tumba 124	F	M-A	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO	N/A	NO	YES	N/A	NO
Azapa 140	Tumba 112A	F	O-A	YES	NO	YES	NO	NO	NO	NO	YES	YES	NO	YES	YES	YES	N/A	YES	NO	NO	NO

Appendix 2: Osteoarthritis of inland agriculturalists

Site	Skeleton ID	Sex	Age	L Acromio-clavicular	L Gleno-humeral	R Acromio-clavicular	R Gleno-humeral	L Humero-radial	L Humero-ulnar	L Radio-ulnar	R Humero-radial	R Humero-ulnar	R Radio-ulnar	L Coxo-femoral	R Coxo-femoral	L Femoro-tibial	L Femoro-patellar	R Femoro-tibial	R Femoro-patellar	L Tibio-astragalina	R Tibio-astragalina
Azapa 140	Tumba 110	F	M-A	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 140	Tumba 126	F	O-A	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	NO	NO
Azapa 140	Tumba XPB 2A	M	Y-A	NO	NO	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Azapa 140	Tumba XPB	F	Y-A	N/A	NO	N/A	NO	NO	NO	NO	N/A	NO	N/A	NO	NO	NO	N/A	NO	NO	NO	NO
Azapa 140	Tumba 41	F	M-A	NO	NO	N/A	NO	YES	YES	NO	N/A	N/A	N/A	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 140	Tumba 50	F	M-A	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	N/A	NO	NO	NO	N/A	N/A	NO
Azapa 140	Tumba 56	F	O-A	NO	YES	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	N/A	YES	N/A	N/A	NO
Azapa 140	Tumba 290	F	Y-A	N/A	N/A	YES	N/A	NO	NO	NO	N/A	N/A	N/A	NO	NO	YES	N/A	NO	N/A	NO	NO
Azapa 140	Tumba 47	F	M-A	N/A	NO	N/A	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	N/A	NO	N/A	NO	NO
Azapa 140	Tumba 42A	F	M-A	N/A	NO	N/A	YES	YES	YES	YES	YES	YES	YES	N/A	YES	YES	YES	YES	YES	N/A	N/A
Azapa 140	Tumba 63	F	M-A	NO	NO	NO	NO	N/A	N/A	N/A	NO	NO	NO	YES	YES	NO	N/A	NO	N/A	NO	NO
Azapa 140	Tumba 111	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Azapa 140	Tumba 79	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Azapa 140	Tumba 78	F	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	NO
Azapa 141	Tumba 22	M	Y-A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	N/A	N/A
Azapa 141	Tumba 33	M	M-A	YES	NO	YES	NO	NO	YES	YES	NO	NO	YES	NO	NO	NO	NO	NO	NO	N/A	NO
Azapa 141	Tumba 36	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N/A	NO	N/A	NO	NO
Azapa 141	Tumba 26	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Azapa 141	Tumba 43	F	M-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	N/A	N/A	N/A	NO	N/A
Azapa 141	Desconocido 02	F	M-A	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	NO	NO
Azapa 141	Tumba 46	M	M-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	N/A	N/A	NO	NO	N/A	NO
Azapa 141	Tumba 52	M	M-A	N/A	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Azapa 141	Tumba 49	F	Y-A	YES	NO	YES	NO	N/A	N/A	N/A	NO	NO	NO	NO	NO	NO	NO	YES	N/A	NO	NO
Azapa 141	Tumba 53	M	Y-A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Azapa 141	Tumba 37	F	M-A	NO	YES	N/A	NO	N/A	N/A	N/A	YES	YES	NO	YES	YES	NO	N/A	NO	NO	NO	NO

Appendix 2: Osteoarthritis of inland agriculturalists